DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
MISSISSIPPI RIVER COMMISSION

SPILLWAY DESIGN FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

MODEL INVESTIGATION

TECHNICAL MEMORANDUM NO. 2-263

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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SYNOPSIS

A model study of the spillway for Whitney Dam, Brazos River, Texas, was conducted on a 1:30-scale section model to determine the performance of the gated crest and the stilling basin. Particular emphasis was placed on selection of a stilling basin which would operate satisfactorily with tailwater depths insufficient for ideal performance of a bucket-type basin and excessive for ideal performance of a conventional hydraulic-jump type basin. Test results indicated that, while the spillway weir as originally designed functioned satisfactorily, the bucket-type energy dissipator was inadequate. Three alternate basin designs were then investigated, incorporating an apron-type basin with two rows of baffle piers and an end sill. Tests of these designs indicated that, while tailwater conditions were slightly higher than required for ideal basin performance, flow conditions in the basin and exit area were superior to those observed with the bucket-type basin. The horizontal apron-type stilling basin found most satisfactory from a hydraulic and economic viewpoint, and designated type 3 design in this report, consisted of an apron 126 ft long, two rows of baffle piers 10 ft high, and an end sill 10 ft high.

SPILLWAY DESIGN FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

Model Investigation

PART I: INTRODUCTION*

1. Whitney Dam, proposed for construction on the Brazos River approximately 38 miles upstream from Waco, Texas, and 81 miles southwest of Dallas, Texas, will be one unit of a thirteen-reservoir system for the control of floods in the Brazos River Valley, and the production of hydroelectric power. Figure 1 is a vicinity map of the area. The project will involve construction of a compacted earthen embankment section, a concrete gravity-type spillway, and two saddle dikes. The dam will have an over-all length of about 17,800 ft and will rise to a height of about 163 ft above the river bed. The reservoir created by the dam will have a total storage capacity of 2,017,500 acre-ft at the top-of-gate elevation. Of the total storage capacity, 1,630,500 acre-ft are for flood control, 131,700 acre-ft for power and 255,300 acre-ft for dead storage.

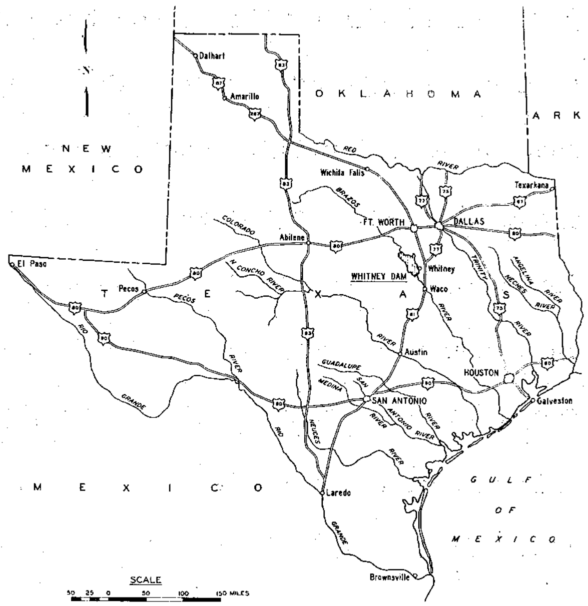

Fig. 1. Vicinity map

* Information on the prototype was obtained from the "Definite Project Report on Whitney Reservoir, Brazos River, Texas."

2. The spillway portion of the dam will be a gravity-type ogee section, 824 ft in length, located in the main river channel adjacent to the power intake structure (see plate 1). The spillway, with crest at elevation 533*, is designed to pass a maximum discharge of 660,000 cfs under a head of 40 ft; the maximum flood of record is 214,000 cfs. Discharges over the spillway will be controlled by seventeen tainter gates, each 40 ft wide and 38 ft high. The piers supporting the gates will be 9 ft thick, which will reduce the spillway from a gross length of 824 ft to a net length of 680 ft. The profile of the spillway, designed for a head of 40 ft, will follow the curve of $\frac{X^2}{121} + \frac{Y^2}{25} = 1$ upstream from the crest and $Y = 0.023579X^{1.833}$ downstream from the crest. Sixteen conduits will be provided for passage of all normal flows of the river and as a means of emptying the flood-control pool prior to the beginning of the next flood season. Each conduit will pass through the base of the spillway directly below a crest pier and will have an invert elevation of 449, a width of 5 ft, and a height of 9 ft. Combined capacity of the conduits with the pool at spillway crest level (elev 533) is 42,200 cfs. Details of the spillway and conduits are shown on plate 2.

3. The following data pertain to the structural and hydraulic features of the spillway and stilling basin:

a. Structural

Length of spillway (gross)	824 ft
Length of spillway (net)	680 ft
Elevation of spillway crest	533.0
Maximum height of spillway	111 ft
Number of crest gates (tainter)	17

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* All elevations are in feet above mean sea level.

Size of gates	40 ft wide by 38 ft high
Elevation of top of gates	571.0
Elevation of energy dissipator	422.0
Number of conduits	16
Size of conduits	5 ft wide by 9 ft high

b. Hydraulic

Maximum spillway discharge	660,000 cfs
Maximum head on spillway crest	40 ft
Maximum pool elevation	573.0
Design head on crest	40 ft
Tailwater elevation (maximum discharge)	497.6
Conduit discharge (pool at spillway crest)	42,200 cfs

4. The powerhouse will be located immediately downstream from and adjacent to the nonoverflow section on the right of the spillway. Contained in the structure will be two turbines and generating units with a capacity of 17,250 kilowatts each. There also will be a small station service turbine and generating unit installed in the powerhouse. Two steel penstocks 14.66 ft in diameter will supply water to the turbines.

5. Although the design of the Whitney Dam structures was based upon sound theoretical design practice, it was desired to check by means of a model study the adequacy of the spillway, and select either a horizontal apron or bucket-type basin to dissipate spillway and sluice discharges. The determining factor in the selection of the stilling basin was the most economical use of the rock underlying the dam site. This rock, located at elevation 422, will provide insufficient tailwater depth for the satisfactory performance of a bucket-type basin and excessive tailwater depths for a standard hydraulic-jump type basin. As a result of these conditions, no predictions could be made as to the individual performance of the two types of energy dissipators. Therefore, selection of the most satisfactory stilling-basin design was to be determined by experimentation.

Authority to undertake the model study was granted by the Chief of Engineers in a teletype dated 7 September 1945 to the District Engineer, Galveston District, CE, Galveston, Texas. The model study was conducted at the Waterways Experiment Station during the period April 1946 to April 1947.

6. During the course of the model study Messrs. M. A. Dillingham, W. E. Wood, and M. J. Newman, of the Galveston District, and Mr. H. W. Feldt of the Southwestern Division visited the Waterways Experiment Station at frequent intervals in an advisory capacity. Engineers of the Experiment Station actively connected with the model study were Messrs. E. P. Fortson, Jr., F. R. Brown, T. E. Murphy, J. C. Goodrum, E. S. Melsheimer, and J. H. Klinck.

PART II: THE MODEL

7. The model of the spillway of Whitney Dam was constructed to a linear-scale ratio of 1:30 and reproduced 500 ft of the approach area, one central gate bay plus adjacent half gate bays, a 98-ft-wide section of the stilling basin and 600 ft of the exit channel (figure 2). For investigation of conduit discharges, three conduits were reproduced and the width of the stilling-basin section increased from 98 ft to 147 ft (figure 3). The model was contained in a reinforced concrete flume. A glass panel was provided in the right wall of the flume in order to observe and photograph the subsurface action of the energy dissipator. That portion of the model upstream from the spillway was molded in cement mortar. The surfaces of the spillway and stilling basin were shaped,

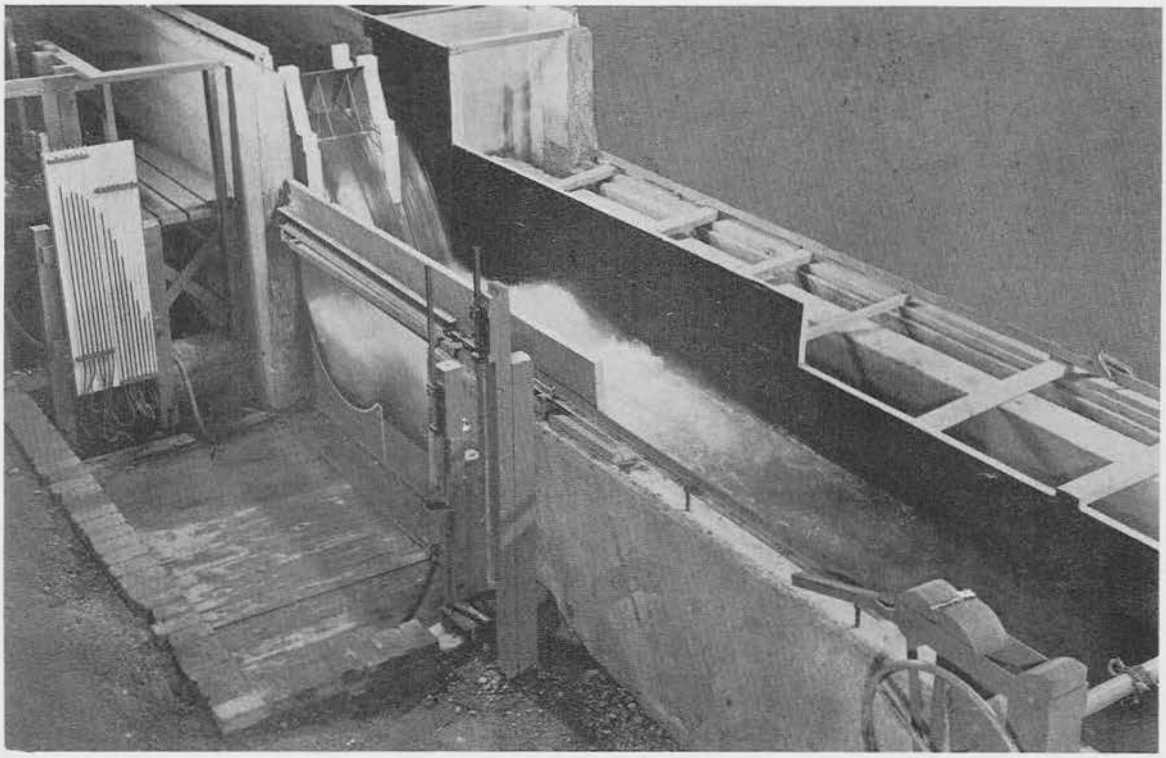


Fig. 2. General view of model, type 1 bucket installed

for the most part, of cement mortar to templets mounted on a steel frame set in concrete. Care was exercised to obtain the proper shape of all surfaces and to make them as smooth as possible. A section of the spillway 4 in. wide, containing the piezometers, was accurately machined of brass in order to insure the exactness of the crest shape, and the piezometers were set precisely at right angles to the surface. The gate piers, apron, baffle piers, and end sill were modeled in wood and treated with a waterproofing compound to prevent expansion. The tainter gates were of machined-metal construction. Conduits through the spillway were fabricated of sheet metal. That portion of the model below the spillway was molded in sand. For velocity measurements the sand bed was rendered immovable by the application of a thin coating of cement mortar.

8. Water used in operation of the model was supplied by pumps with measurement of quantity being made by venturi meters. Flow from the supply lines spilled into a headbay where it was stilled by baffles prior to its

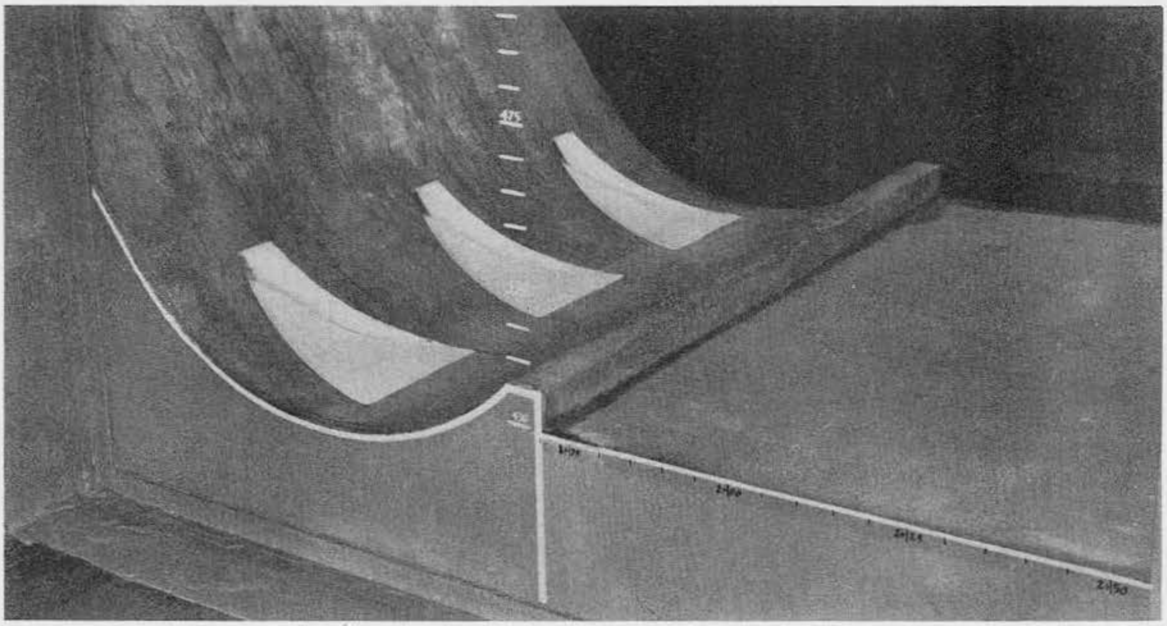


Fig. 3. Type 1 bucket

entrance into the model. After passing through the model the water flowed through a return line to the storage sump. The tailwater elevation in the downstream end of the model was controlled by means of an adjustable tailgate. Steel rails, set to grade along either side of the model, provided a datum plane for the use of measuring devices. Water-surface elevations were measured both by means of portable point gages (mounted on an aluminum beam supported by the steel rails) and by means of piezometers. Velocities were measured by means of a pitot tube. Pressures over the spillway were measured in manometers connected by tubes to piezometer openings in the model. Soundings over the sand bed downstream from the basin were procured by means of a portable sounding rod.

9. The accepted equations of hydraulic similitude, based upon the Froudian relationships, were used to express the mathematical relationships between the dimensions and hydraulic quantities of the model and the prototype. The general relationships are presented in the following table:

Dimension	Scale Ratio
Length	$L_r = 1:30$
Area	$A_r = L_r^2 = 1:900$
Velocity	$V_r = L_r^{1/2} = 1:5.477$
Discharge	$Q_r = L_r^{5/2} = 1:4929$

10. Measurements in the model of discharges, water-surface elevations, velocities, and pressures (all positive pressures and negative pressures corresponding to pressures above the cavitation range in the prototype) may be transferred quantitatively from model to prototype by means of the preceding scale relationships. Evidences of scour may be

considered only as qualitatively reliable since it has not yet been proven possible to simulate quantitatively in a model the resistance to erosion of a prototype bed material. Actual depths of scour in the prototype can only be estimated from the magnitude and direction of bottom velocities (which are quantitatively determinable).

PART III: TESTS AND RESULTS

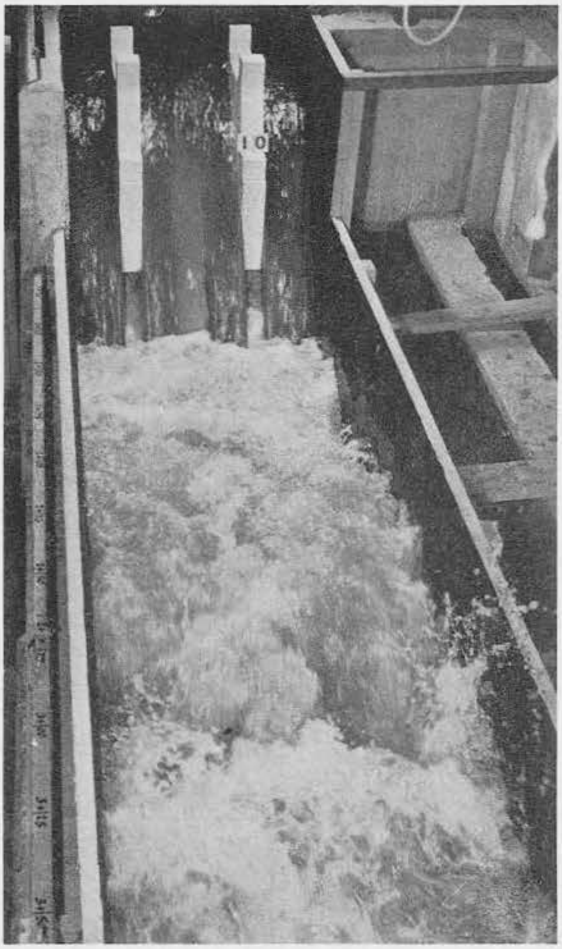
Spillway Weir

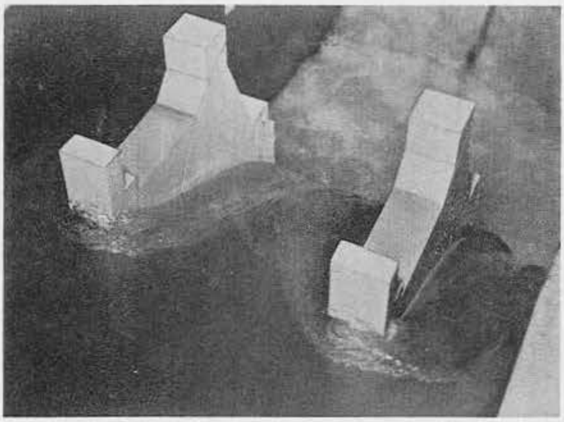
Description

11. As mentioned previously, the masonry profile of the spillway weir was based on a design head of 40 ft. The upstream face of the weir was joined to the crest by an elliptical curve with semi-major axis (X) equal to 11 ft and semi-minor axis (Y) equal to 5 ft. Downstream from the crest the masonry profile was based on the equation $Y = 0.023579X^{1.833}$ which became tangent to a 10 vertical on 7 horizontal face slope. The profile conforms closely with Bazin's lower nappe curve for a sharp-crested weir with vertical face under a head of 40 ft. The face slope was joined to the stilling basin or bucket by means of a circular curve with a radius of 50 ft. Crest piers, supporting the tainter gates, were 9 ft thick, and were semicircular in shape on the upstream end and square on the downstream end. The gates were 40 ft wide, 38 ft high, and curved on a radius of 38 ft; they were seated 10.75 ft downstream from the crest of the spillway. No alterations were made to the spillway weir during the model study.

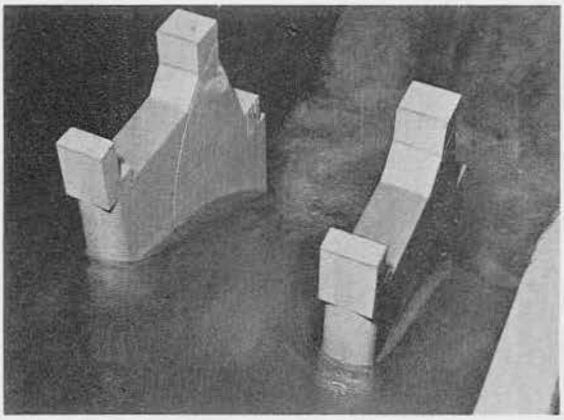
Test results

12. Flow conditions. Satisfactory flow conditions obtained over the spillway weir throughout the range in discharge. The contraction effect of the gate piers was clearly noted, particularly at high discharges where flow piled against the upstream nose of the piers and caused an unevenness in the surface of the nappe between the piers and





Discharge 660,000 cfs



Discharge 660,000 cfs

Discharge 250,000 cfs

Fig. 4. Flow over spillway weir

downstream therefrom (figure 4). Flow was marked by fluctuations which are characteristic of discharges over structures of this type, and the 9-ft-wide gate piers kept the jets separated throughout the greater part of their descent toward the stilling basin.

13. Weir calibration. Discharge over the spillway was computed by the conventional weir formula:

$$Q = C(L - KNH)H^{3/2}$$

where Q = discharge in cfs

C = coefficient of discharge which varies with relation between actual head and design head on weir

L = length of spillway crest (total length less pier widths)

K = a constant, the value of which depends upon the shape of the abutment and piers (assumed to be 0.02 for the computed coefficient curve and 0.015 for the coefficient curve based on model data)

N = the number of contractions, depending upon the number of crest piers

H = the total head on the spillway crest.

Computations were based on a discharge coefficient "C" which varied from 3.09 at zero head to 4.0 at the design head of 40 ft. The computed curve indicates a discharge of 400,000 cfs with a pool at elevation 562.5 (29.5-ft head) and a discharge of 660,000 cfs with a pool at elevation 573.0 (40-ft head). Similar discharges were passed in the model at pool elevations of 562.2 and 572.1, respectively. A plot of head-discharge relations, both model and computed, is presented on plate 3. Also shown are plots of coefficient values.

14. Gate calibration. Head-discharge relations determined for the partial opening of one gate and various discharges are shown on plate 4. The test data revealed that the discharge for one gate fully open with the pool at elevation 571 (top of gates) was 35,200 cfs or 598,400 cfs for seventeen gates computed on this basis. Computations indicated a discharge of 35,800 cfs per gate with the pool at top of gates. For conditions of partial opening where the pool elevation was such that the spillway nappe just touched the gate lip, it was found that results varied considerably, depending upon whether the pool was falling or rising. On a falling pool the spillway nappe clung to the gate lip, resulting in

orifice-type flow. On a rising pool and at the same head the spillway nappe did not impinge on the gate lip, resulting in free flow and an increased discharge. As the pool continued to rise, however, the nappe touched the gate lip, resulting in a sudden decrease in capacity. This region of instability where the head and discharge are dependent upon a rising or falling pool is shown as a shaded area on plate 4.

15. Water-surface and pressure profiles. Water-surface and pressure profiles were measured over the spillway for a complete range of uncontrolled discharges from 660,000 cfs to 50,000 cfs. Pressures also were recorded with the pool at elevation 571 and partial gate openings varying from 1 ft to 24 ft. Typical plots of these data are shown on plates 5-9 and in table 1. For uncontrolled overflow a negative pressure of -0.5 ft of water was measured at piezometer 9 for the maximum discharge of 660,000 cfs; all other pressures were positive. For conditions of partial gate opening, a maximum negative pressure equivalent to -2.3 ft of water was recorded at piezometer 9 for gate openings of 12, 15, and 18 ft.

Conduits

Description

16. To provide control of flood releases at low pool levels, sixteen conduits will be located through the spillway directly below each crest pier. The conduits will be 5 ft wide by 9 ft high and are designed to discharge a combined flow of approximately 42,200 cfs with reservoir pool at the spillway crest, elevation 533.0. Plate 11 shows detailed dimensions. The entrance curves of the top, bottom and sides of the conduit

were shaped to the elliptical curve of $(\frac{X}{5})^2 + (\frac{Y}{1.5})^2 = 1$ to insure maximum efficiency and to help prevent cavitation. To further aid in the prevention of cavitation, the roofs of the conduits near the exits were depressed and the exit area reduced about 11 per cent in area to 40 sq ft or a section 8.9 ft wide by 4.5 ft high. Flow through the conduits will be controlled by hydraulically-operated slide gates. Where the conduits emerge in the basin the side walls will be flared to permit the outflowing stream to spread, thus lessening its "jetting" through the tailwater.

Test results

17. Flow conditions. Flow conditions at the conduit intakes, through the conduits, and at the exit portals appeared satisfactory for all conditions of discharge. Flow conditions as they affect stilling-basin performance are discussed in later paragraphs.

18. Conduit calibration. The conduits were calibrated for various discharge and tailwater conditions. Initial tests, the results of which are shown on plate 10, were conducted without tailwater over the exit portals. As shown on the referenced plate, model and computed results were in close agreement. At the top-of-gate elevation the computed curve indicates a discharge of 50,000 cfs through sixteen conduits whereas model results indicated a discharge of about 48,000 cfs. However, the use of tailwater (plate 12) set in accordance with the flow being passed through the conduits resulted in a steadily increasing divergence between computed and model calibration values. Calibration data procured with the bucket-type energy dissipator in place and tailwater depths set in accordance with the discharge are tabulated below:

Discharge cfs	Number of Conduits	Pool Elevation Computed	Pool Elevation Model	Tailwater Elevation
5,000	2	523.5 ft	526.70 ft	431.40 ft
20,000	8	523.5 ft	528.95 ft	438.35 ft
20,000	12	479.7 ft	480.68 ft	438.35 ft
30,000	12	523.5 ft	529.25 ft	442.28 ft
36,000	12	560.5 ft	570.50 ft	444.40 ft
30,000	16	488.0 ft	493.30 ft	442.28 ft
40,000	16	523.5 ft	533.75 ft	445.60 ft
50,000	16	570.8 ft	587.30 ft	448.35 ft

19. Pressures. Measurements of pressures throughout one of the conduits for various discharges revealed that, with the exception of a discharge of 1,500 cfs, pressures throughout the conduit were positive. At a discharge of 1,500 cfs a negative pressure of -5.0 ft was recorded at the conduit intake (piezometer 1) and -6.5 ft on the top of the conduit (piezometer 6). Actual pressure measurements and piezometer location at which they were procured are shown on plate 11. For these tests the tailwater was lowered until the exit portals were free, thus preventing any backwater effect of tailwater and reduction of discharge.

Stilling Basin

20. Plate 13 presents details of all energy dissipators investigated during the course of the model study. As previously explained, all basins were located at elevation 422 to take advantage of natural foundation conditions at that level. With the stilling basin located at this elevation, however, tailwater depths, for the most part, were in excess of those required for the dissipation of energy by means of a hydraulic jump. Plate 12 shows the estimated present tailwater depth at the dam site, together with the theoretical depth required for the formation of a hydraulic jump with various combinations of gates in operation.

21. Complete investigation of each type stilling basin involved study of spillway and conduit discharges and their effects on basin performance. Since conduit discharges will occur the greatest percentage of the time, considerable emphasis was placed on these flows in the selection of a stilling-basin design.

Description -- type 1 bucket

22. Since tailwater depths for spillway flows were excessive for the design of a hydraulic-jump basin, the energy dissipator originally proposed was of the bucket type (figure 3). The bucket had a radius of curvature of 50 ft, an invert elevation of 422, lip height of 14.6 ft, and lip slope of 1 on 1. For all tests the bed of the exit area was molded to elevation 430.

Test results -- type 1 bucket (spillway discharge)

23. Flow conditions in the type 1 bucket under spillway discharges are presented on photograph 1, while water-surface profiles, subsurface currents, bottom velocities and scour patterns for various discharge conditions are presented on plates 14-18. Data presented are discussed briefly in the following paragraphs.

24. Observation of flow conditions in the bucket of original design revealed that the action was typical of a bucket-type energy dissipator in that a large standing wave was formed above the bucket lip with an elliptical surface roller above the bucket and a ground roller downstream therefrom. The standing wave over the bucket lip was violent and unstable at high discharges, but under no conditions could the jet be forced by artificial means or unbalanced gate operation to dive

beneath the tailwater and remain along the bed of the channel. At low discharges bucket action was good; the standing wave was smaller, more stable and less violent. Measurement of water-surface profiles indicated that at the maximum discharge of 660,000 cfs there was a difference in the water-surface elevation over the bucket and the top of the standing wave of about 30 ft; this difference was reduced to about 8 ft at a discharge of 50,000 cfs.

25. From an inspection of velocity distribution in the bucket, it would appear at first as though no energy dissipation took place, since the flow entered the bucket and was diverted at about the same velocity (maximum velocities were in the range of 75 ft per sec). Actually, however, the high-velocity flow was divided into two parts by the bucket lip, one part forming the surface roller and the other the ground roller. Evidence of such dissipation with the surface roller and ground roller was provided by the excessive turbulence in the bucket, and by the reduction in bottom velocities downstream from the bucket. The maximum bottom velocities occurred at a discharge of 660,000 cfs and were 30 and 25 ft per sec in the ground roller and downstream therefrom. These data also revealed that for discharges of 660,000 and 50,000 cfs, the downstream limits of the ground rollers were about 120 and 20 ft, respectively, downstream from the lip of the bucket.

26. Scour data procured indicated excessive erosion about 100 ft downstream from the bucket at high flows. For discharges of 660,000 and 450,000 cfs the concrete bed of the model located at elevation 385 was exposed, indicating a scour depth of 45 ft. At lower discharges the amount of erosion was decreased. At all discharges the ground roller

created downstream from the bucket kept material banked against the lip of the bucket. In analyzing scour data, it is desired to emphasize that the scour patterns presented indicate the location of the scouring attack rather than its magnitude; the magnitude of scour should be analyzed in view of the bottom velocities and resistance to erosion of prototype bed material. The scour data also form the basis for comparison of the stilling effect of the various model basins.

Test results -- type 1 bucket (conduit discharge)

27. Observation of flow conditions in the bucket with conduit discharge and pool elevation at top of gates revealed that spray conditions existed unless the tailwater was set to simulate the flow from sixteen conduits (photograph 2). For low pool elevations flow was confined to the bucket. In the analysis of test results of the type 1 bucket and all other energy dissipators described in succeeding paragraphs serious consideration should be given to basin performance under conduit flow, since the basin will be subjected to these flows the greatest percentage of the time.

28. Water-surface profiles, velocities, and scour data procured for conduit discharges are presented on plates 19-26. The water-surface profiles indicated the existence of spray conditions at high pool levels, as shown by the photographs. Velocity and scour data revealed that when spray conditions existed velocities and erosion in the exit area were increased considerably. For a discharge of 30,000 cfs through twelve conduits and a pool elevation of 529.25, it was possible for spray or roller action conditions to exist, depending upon whether the pool was

rising or falling. Data procured under both conditions of bucket action revealed that velocities were increased from 3 ft per sec under conditions of roller action to as much as 28 ft per sec under spray conditions.

Description -- type 1 apron

29. Since flow conditions with the bucket-type basin were inadequate for high spillway discharges and unsatisfactory for low conduit discharges at high pool levels, attempts were made to effect improvements by use of an apron-type stilling basin (plate 13). Although the apron was below the theoretical elevation required for hydraulic-jump formation, it was planned to dissipate the energy of flow from the spillway and conduits by roller action abetted by baffle piers and an end sill. The type 1 apron design consisted of a horizontal apron 200 ft in length at elevation 422, two rows of baffle piers 10 ft high and a 10-ft stepped sill.

Test results -- type 1 apron (spillway discharge)

30. Flow conditions for discharges of 660,000, 250,000, and 50,000 cfs over the spillway are shown by photograph 3. Due to the limited length of the glass panel, only action over the apron between the toe of the spillway and the downstream row of baffle piers is shown. However, water-surface profiles and subsurface currents presented on plates 27-29 indicate excellent stilling-basin performance. As planned, the baffle piers and end sill served to deflect all bottom currents away from the bed of the exit area. This method of energy dissipation resulted in the deflected currents being spread over a large portion of the basin instead of being concentrated in the form of a high wave as was the case with the bucket-type basin. Impact of flow on baffle piers or end sill

did not appear excessive.

31. Examination of the velocity data shown reveals the effectiveness of the type 1 apron in reducing velocity of flow at all discharges. The highest velocity measured in the exit area at the maximum discharge of 660,000 cfs was 8.5 ft per sec. For discharges of 250,000 and 50,000 cfs the highest velocities measured were 5.5 ft per sec and 1.0 ft per sec, respectively. A comparison of these velocities with those of the type 1 bucket (plates 14, 16, 18), where velocities of 30, 18, and 3 ft per sec were recorded for similar discharges, clearly indicates the superiority of the apron-type basin.

32. Scour data were in agreement with velocity data in that little erosion of the model bed occurred. At the maximum discharge of 660,000 cfs the greatest depth of erosion recorded was 14 ft as compared to 45 ft recorded below the type 1 bucket. For discharges of 250,000 and 50,000 cfs scour was negligible, ranging in depth from 2 ft to zero, respectively.

Test results -- type 1 apron (conduit discharge)

33. Observation of flow conditions in the type 1 apron design with conduit discharges (photographs 4 and 5) revealed satisfactory performance for all conditions of discharge and combinations of conduits in operation. For the most part, all energy was dissipated by the time the jets issuing from the conduits had reached the vicinity of the baffle piers.

34. Water-surface profiles, velocities, and scour measurements are shown on plates 30-34. It is to be noted from these data that conditions in the exit area were more critical than with spillway discharges. The

maximum velocity recorded was 10.5 ft per sec with three conduits in operation.

Description -- type 2 apron

35. Although the performance of the type 1 apron was very satisfactory in the dissipation of spillway and conduit discharges, it was believed that a reduction in apron length would permit comparable basin performance and at the same time effect economies in construction. Therefore, the type 1 apron was reduced in length from 200 to 146 ft and designated the type 2 apron. The baffle piers and end sill also were moved upstream by the decrease in apron length. Plate 13 presents details of the type 2 apron design.

Test results -- type 2 apron (spillway discharge)

36. Flow conditions existing over the type 2 apron for discharges of 660,000, 250,000, and 50,000 cfs are shown on photograph 6. Observations indicated equal, if not more satisfactory, performance than was noted with the type 1 apron installed. Location of the baffle piers nearer the toe of the spillway resulted in more deflection of flow away from the bed of the exit area.

37. Water-surface profiles, velocity, and scour data for various discharges are presented on plates 35-37. Comparison of these data with those procured with the type 1 apron shows a decided similarity. Although the shorter apron resulted in a slightly higher water-surface elevation over the end sill, the maximum bottom velocity recorded at the maximum discharge was 7 ft per sec as compared to 8 ft per sec recorded below the type 1 apron. Erosion tests indicated that the type 2 apron afforded

about the same degree of protection as the type 1 apron, although slightly more material was deposited behind the end sill with the type 1 apron installed.

Test results -- type 2 apron (conduit discharge)

38. Flow conditions, water-surface profiles, velocity and scour data with conduit discharges are shown on photographs 7 and 8 and plates 38-42. These data indicate results somewhat comparable to those observed below the type 1 apron when subjected to similar conditions. Velocities below the type 2 basin tended to be 1 to 2 ft per sec greater and about 2 ft more erosion of the model bed occurred.

Description -- type 3 apron

39. In an attempt to further reduce the length of the apron-type basin, the type 3 apron design was evolved. The design was similar to the type 2 apron with the exception that the length was reduced about 20 ft and the basin elements rearranged. Tests included study of the effectiveness of different size baffle piers and end sills in dissipating energy of spillway flow; the baffle piers also were removed from the apron to determine their effect on basin performance.

Test results -- type 3 apron (spillway discharge)

40. Flow conditions for discharges of 660,000, 250,000, and 50,000 cfs over the spillway are shown on photograph 9. Observations indicated that basin performance with the shortened apron of type 3 design was equally as efficient as the performance of types 1 and 2 designs. Also it was observed that a reduction in the height of the baffle piers and

end sill from 10 ft to 6 ft did not have any appreciable effect (photographs 9 and 10). Moving the baffle piers upstream resulted in a more effective use of the piers in deflecting bottom currents away from the exit area (plates 43-45). With the baffle piers eliminated entirely, flow was deflected from the bed of the exit channel by the end sill. Photograph 10 shows flow conditions with the baffle piers omitted for two end-sill heights and an intermediate discharge.

41. Comparison of the velocity data shown on plates 43-45 with similar data obtained with other basin designs installed reveals that all basins of the apron type investigated afforded about the same degree of protection. The highest velocity measured in the area downstream from the end sill was 7 ft per sec in an upstream direction at the maximum discharge of 660,000 cfs. No velocity measurements were made with the type 3 basin and baffle piers and end sill reduced in height to 8 and 6 ft or eliminated entirely. Study of the effect of reducing the height of baffle piers and end sill should be predicated upon the scour results presented in the following paragraphs.

42. Results of erosion tests (plates 43-53) indicated that at the maximum discharge scour was less than observed previously with the longer basins. This is attributed to the greater effect of the baffle piers in their upstream position on the dissipation of spillway flows. For lower discharges the amount of scour was about the same as observed with previous apron designs. As the height of the baffle piers and end sill was reduced the amount of erosion progressively increased. Elimination of the baffle piers entirely, however, resulted in less scour than was observed below the bucket-type energy dissipator.

Test results -- type 3 apron (conduit discharge)

43. Observation of flow conditions in the type 3 apron design with conduit discharges revealed that, as in previous instances, dissipation of conduit flow was more critical than spillway flow. Flow conditions for various discharges and combinations of conduits in operation are shown on photographs 11 and 12 and on figure 5. The photographs indicate that for conditions of one conduit in operation the baffle piers in the upstream row are subject to impact. However, for all conditions flow was confined to the basin and no spray action resulted as was the case with the bucket-type energy dissipator.

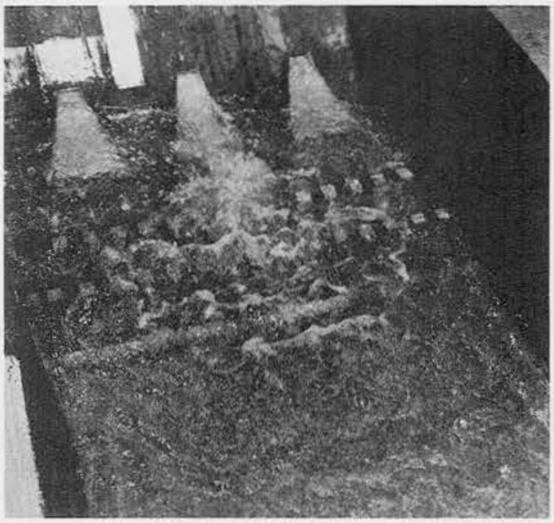


Fig. 5. Type 3 apron
1 conduit, discharge 3,000 cfs

44. Water-surface profiles, velocity and scour measurements are shown on plates 54-58. The maximum velocity recorded was 13.5 ft per sec for conditions of one conduit discharging 3,000 cfs. Velocities and scour conditions were about the same with one conduit in operation or with three adjacent conduits discharging 9,000 cfs.

PART IV: DISCUSSION OF TEST RESULTS

45. From the test results described in preceding paragraphs it will be noted that the model indicated the desirability of revising the stilling-basin design while confirming the adequacy of the original spillway weir. The spillway demonstrated by model tests to operate most satisfactorily consisted of an ogee-type weir with a gross crest length of 824 ft at elevation 533, and a stilling basin with a horizontal apron 126 ft long at elevation 422, two rows of baffle piers and a stepped end sill each 10 ft high.

46. Flow over the ogee-type spillway section of original design appeared to be satisfactory for all conditions of free and controlled overflow. The spillway rating curve, as determined in the model, indicated that more flow could be passed at high pool stages than was expected from computations. At the maximum discharge of 660,000 cfs the pool elevation in the model for conditions of free overflow was 572.1 as compared to the computed elevation 573.0. Pressures over the weir surface were for the most part positive. For conditions of maximum flow a negative pressure of -0.5 ft of water was recorded at one point and for conditions of large partial gate openings a negative pressure of -2.3 ft was recorded. These negative pressures are not excessive, however, and should cause no concern.

47. Tests of the stilling basin demonstrated the superiority of the horizontal apron-type energy dissipator over the bucket type, especially for the dissipation of conduit flow. With the bucket-type energy dissipator installed, it was observed that spray action resulted for most

conditions of conduit flow. Similar conditions of conduit flow into the horizontal apron-type basin caused all flow to be dissipated within the basin proper. Conditions in the apron-type basin were most critical for one or three adjacent conduits operating, in that energy dissipation was accomplished in part by impact on the upstream row of baffle piers. However, the baffle piers were cushioned somewhat by the overlying tailwater and no damage should result. Bottom velocities recorded in the exit channel did not exceed 13 ft per sec. Although for spillway discharges the bucket-type energy dissipator operated as planned, energy dissipation was not as complete as with the horizontal apron-type basin installed. Flow conditions over the bucket and in the exit area also were violent and marked by high waves. For maximum discharge conditions bottom velocities in the exit channel, although upstream in direction, reached a magnitude of 30 ft per sec. For similar discharge conditions, a maximum bottom velocity of 7 ft per sec was recorded below the apron-type basin (type 3). Whether economies to be effected by construction of the bucket-type energy dissipator will offset the greater protection to be secured through use of an apron-type basin is not known.

48. The various tests on the apron-type basin demonstrated that it was possible to shorten the apron of initial design by 74 ft without reducing its efficiency in the dissipation of either spillway or conduit flows. With the shortened apron, the 10-ft baffle piers and end sill were rearranged to more fully utilize the baffle piers in stabilizing the position of the hydraulic jump. The tests also indicated that satisfactory basin performance could be obtained with baffle piers and end sill as low as 6 ft in height; fair performance was obtained with the baffle piers

removed from the apron entirely. However, it was observed for conditions of tailwater slightly above normal that spillway flow had a tendency to submerge and attack the bed of the exit channel. Therefore, it is recommended that baffle pier and end sill heights on the type 3 apron be at least 8 ft and preferably 10 ft for completely satisfactory basin performance. Although all tests were conducted with stepped-type baffle piers and end sill, it is believed that vertical-faced piers or end sill would function equally well.

TABLES

TABLE 1

CREST PRESSURES FOR PARTIAL GATE OPENINGS

Piez. No.	Piez. Zero	24-Ft Opening		18-Ft Opening		15-Ft Opening		12-Ft Opening		9-Ft Opening	
		Discharge = 27,300 cfs Pool Elev = 571.0		Discharge = 21,000 cfs Pool Elev = 571.0		Discharge = 18,000 cfs Pool Elev = 571.0		Discharge = 14,000 cfs Pool Elev = 571.0		Discharge = 10,550 cfs Pool Elev = 571.0	
		Piez. Reading	Pressure	Piez. Reading	Pressure	Piez. Reading	Pressure	Piez. Reading	Pressure	Piez. Reading	Pressure
1	528.0	565.5	37.5	568.0	40.0	569.4	41.4	570.1	42.1	571.0	43.0
2	530.0	557.0	27.0	562.5	32.5	564.9	34.9	567.1	37.1	569.6	39.6
3	531.5	557.3	25.8	562.5	31.0	564.8	33.3	566.9	35.4	569.0	37.5
4	532.5	555.8	23.3	560.5	28.0	562.8	30.3	565.4	32.9	568.0	35.5
5	533.0	551.6	18.6	556.3	23.3	558.7	25.7	561.4	28.4	564.8	31.8
6	532.5	545.8	13.3	548.6	16.1	550.2	17.7	552.3	19.8	555.8	23.3
7	530.5	536.7	6.2	535.8	5.3	535.3	4.8	534.5	4.0	553.7	23.2
8	527.0	531.1	4.1	529.2	2.2	528.6	1.6	527.9	0.9	527.4	0.4
9	521.0	519.9	-1.1	518.7	-2.3	518.7	-2.3	518.7	-2.3	518.9	-2.1
10	513.0	513.6	0.6	513.4	0.4	513.1	0.1	513.0	0.0	513.1	0.1
11	504.0	505.3	1.3	504.7	0.7	504.4	0.4	504.2	0.2	504.3	0.3
12	491.0	491.1	0.1	491.0	0.0	490.3	-0.7	490.7	-0.3	490.4	-0.6
13	476.0	481.3	5.3	481.0	5.0	480.0	4.0	479.7	3.7	479.2	3.2
14	460.0	466.0	6.0	465.5	5.5	464.7	4.7	464.0	4.0	463.8	3.8
15	445.0	464.2	19.2	461.3	16.3	460.0	15.0	458.3	13.3	455.8	10.8

Discharges based on flow through one gate.
Pressures shown in prototype feet of water.
Piezometer locations shown on plate 5.

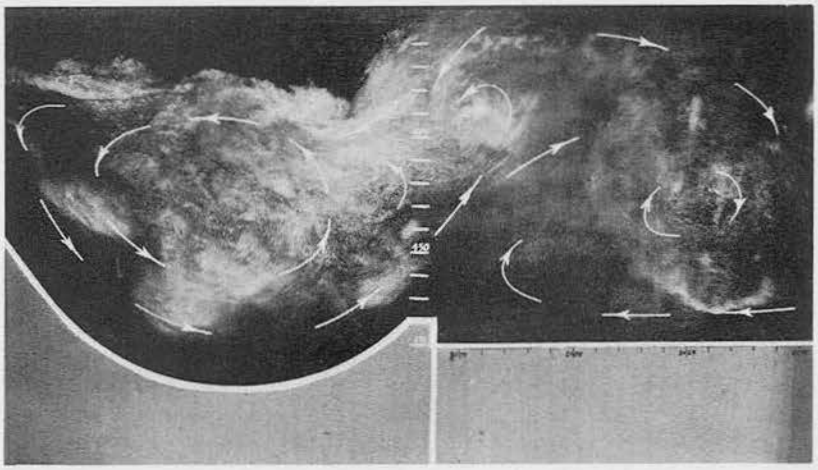
TABLE 1 (Continued)

CREST PRESSURES FOR PARTIAL GATE OPENINGS

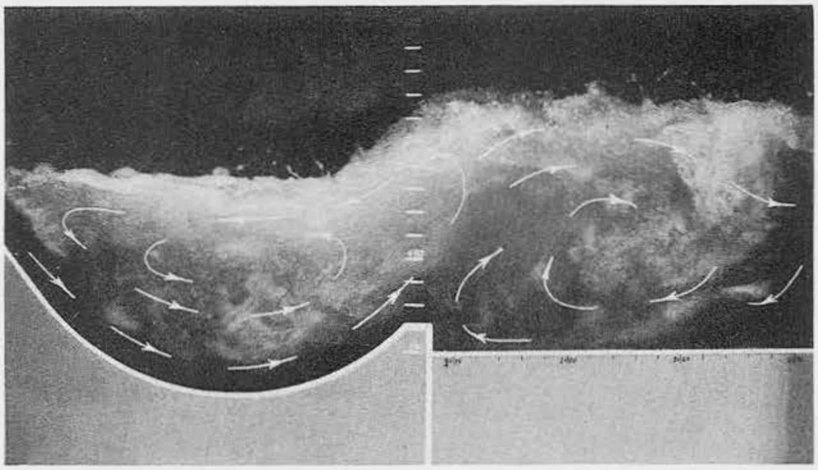
Piez. No.	Piez. Zero	6-Ft Opening Discharge = 6,930 cfs Pool Elev = 571.0		4-Ft Opening Discharge = 4,700 cfs Pool Elev = 571.0		3-Ft Opening Discharge = 3,500 cfs Pool Elev = 571.0		2-Ft Opening Discharge = 2,400 cfs Pool Elev = 571.0		1-Ft Opening Discharge = 1,400 cfs Pool Elev = 571.0	
		Piez. Reading	Pressure	Piez. Reading	Pressure	Piez. Reading	Pressure	Piez. Reading	Pressure	Piez. Reading	Pressure
1	528.0	571.5	43.5	571.9	43.9	571.9	43.9	572.1	44.1	572.1	44.1
2	530.0	570.5	40.5	571.2	41.2	571.4	41.4	571.9	41.9	572.0	42.0
3	531.5	570.5	39.0	571.0	39.5	571.3	39.8	571.9	40.4	572.0	40.5
4	532.5	570.0	37.5	570.9	38.4	571.2	38.7	571.9	39.4	572.0	39.5
5	533.0	568.5	35.5	570.3	37.3	571.1	38.1	571.8	38.8	572.0	39.0
6	532.5	561.0	28.5	565.8	33.3	568.2	35.7	570.6	38.1	571.7	39.2
7	530.5	532.0	1.5	531.2	0.7	530.6	0.1	530.2	-0.3	530.4	-0.1
8	527.0	527.0	0.0	527.6	0.6	527.3	0.3	527.3	0.3	527.6	0.6
9	521.0	519.2	-1.8	519.9	-1.1	520.0	-1.0	520.4	-0.6	521.0	0.0
10	513.0	513.0	0.0	513.3	0.3	513.4	0.4	513.3	0.3	513.5	0.5
11	504.0	504.1	0.1	504.6	0.6	504.5	0.5	504.6	0.6	504.6	0.6
12	491.0	490.3	-0.7	490.7	-0.3	490.8	-0.2	490.9	-0.1	491.2	0.2
13	476.0	477.8	1.8	477.8	1.8	477.5	1.5	477.0	1.0	476.8	0.8
14	460.0	462.8	2.8	462.6	2.6	462.4	2.4	462.0	2.0	461.8	1.8
15	445.0	452.0	7.0	450.1	5.1	449.1	4.1	448.2	3.2	447.0	2.0

Discharges based on flow through one gate.
Pressures shown in prototype feet of water.
Piezometer locations shown on plate 5.

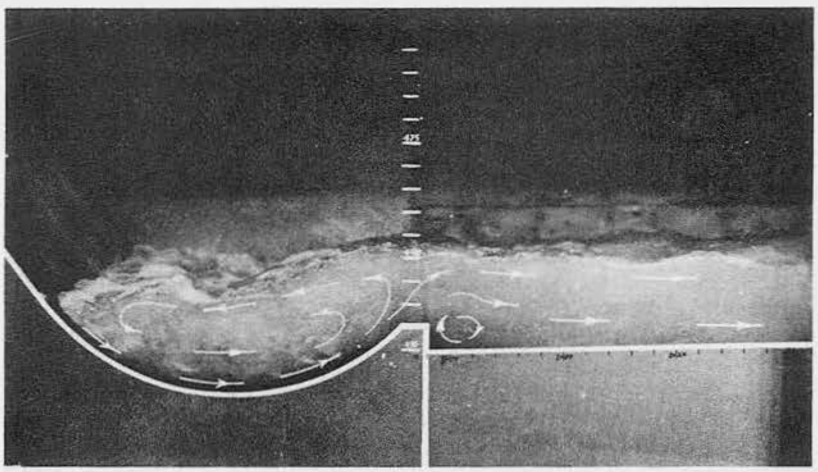
PHOTOGRAPHS



Discharge 660,000 cfs; TW elev 497.6; pool elev 572.12

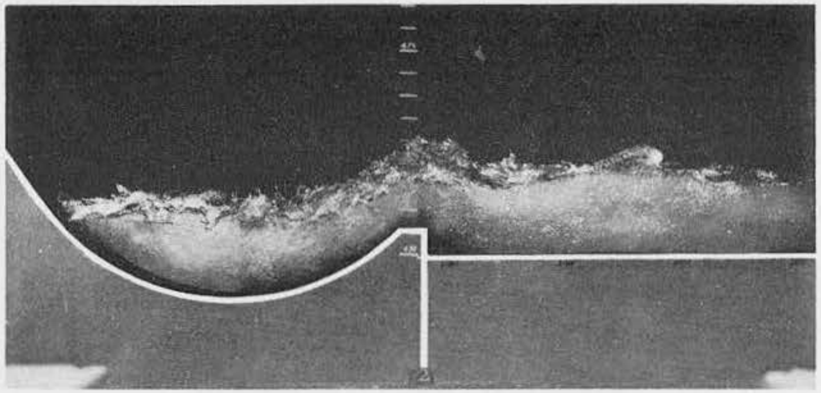


Discharge 250,000 cfs; TW elev 475.4; pool elev 555.03

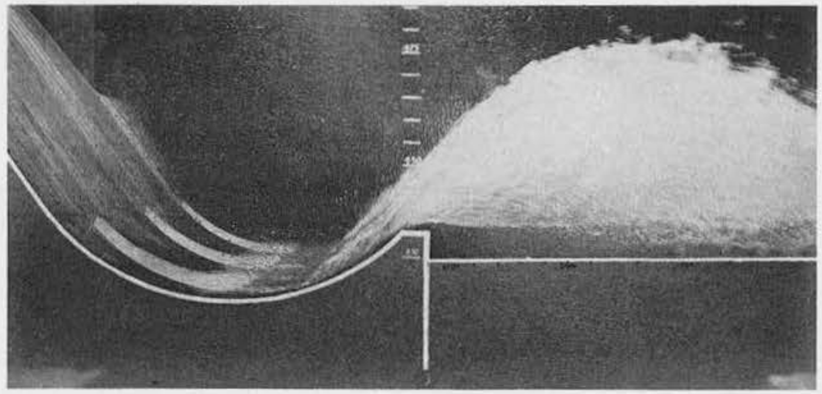


Discharge 50,000 cfs; TW elev 448.3; pool elev 540.86

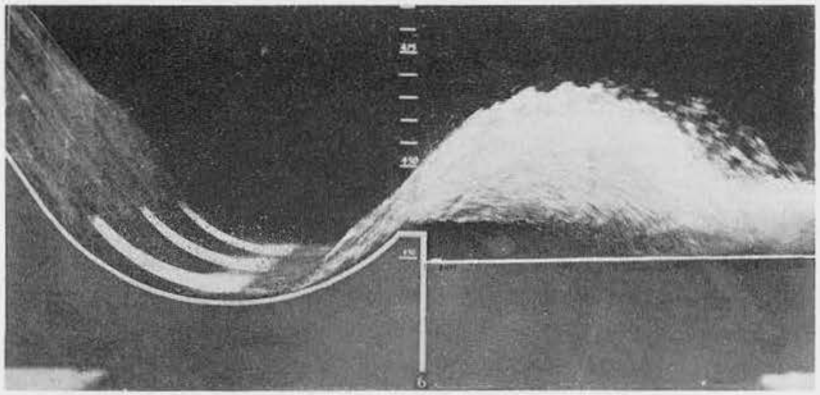
PHOTOGRAPH 1. Flow conditions -- type 1 bucket and various spillway discharges



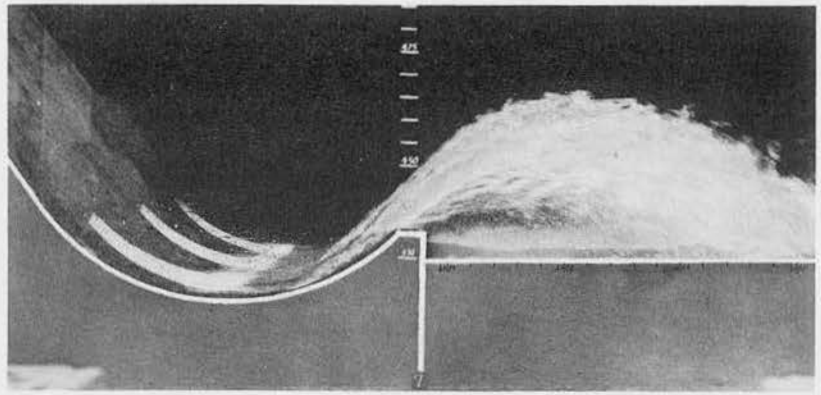
16 conduits
Discharge 50,000 cfs; tailwater elev 448.3
Pool elev 587.30



12 conduits
Discharge 36,000 cfs; tailwater elev 444.4
Pool elev 570.50

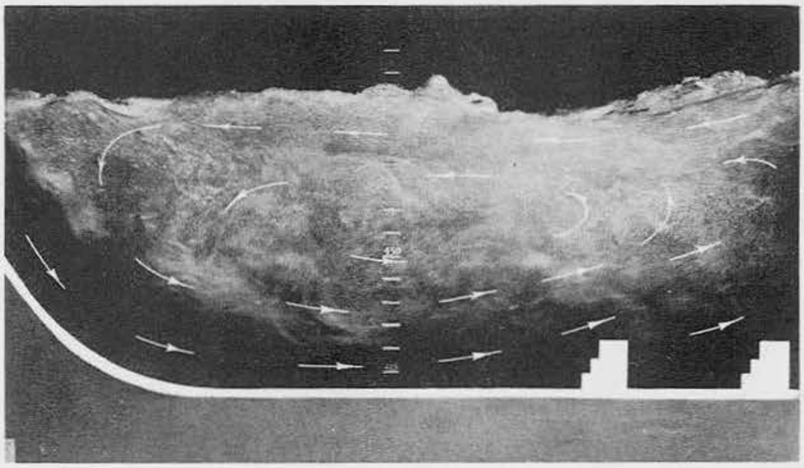


12 conduits
Discharge 30,000 cfs; tailwater elev 442.3
Pool elev 529.25

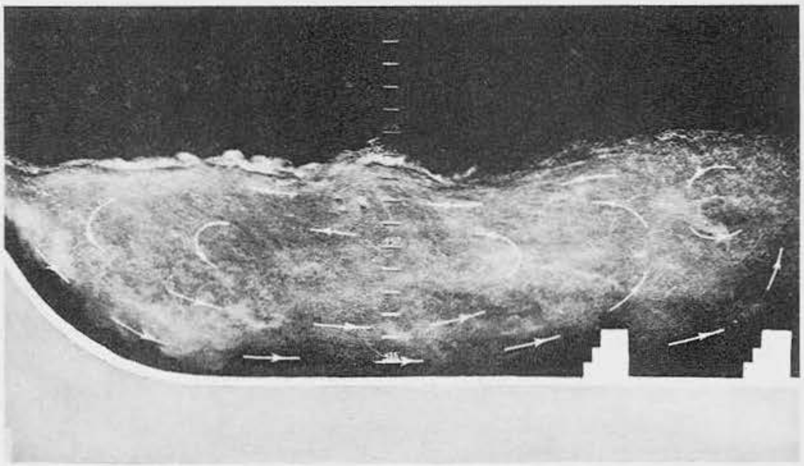


8 conduits
Discharge 20,000 cfs; tailwater elev 438.4
Pool elev 528.95

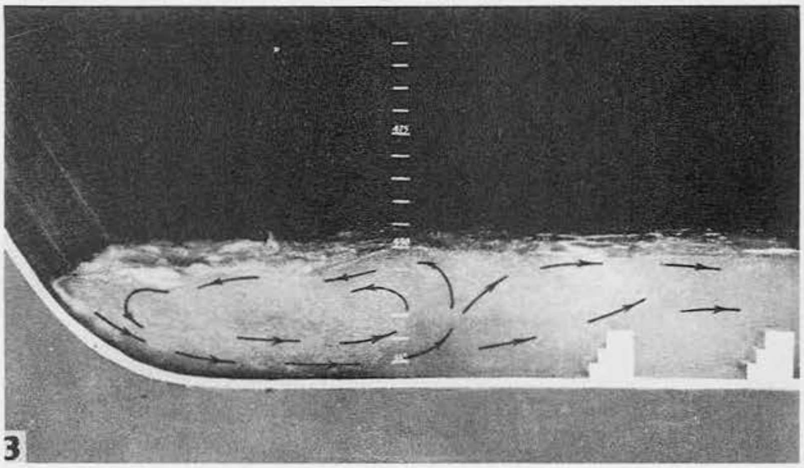
PHOTOGRAPH 2. Flow conditions -- type 1 bucket and various conduit discharges



Discharge 660,000 cfs; TW elev 497.6; pool elev 572.12

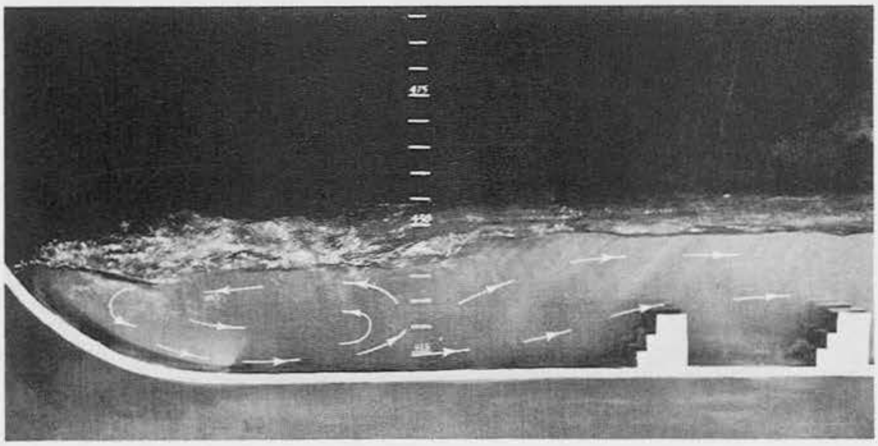


Discharge 250,000 cfs; TW elev 475.4; pool elev 555.03

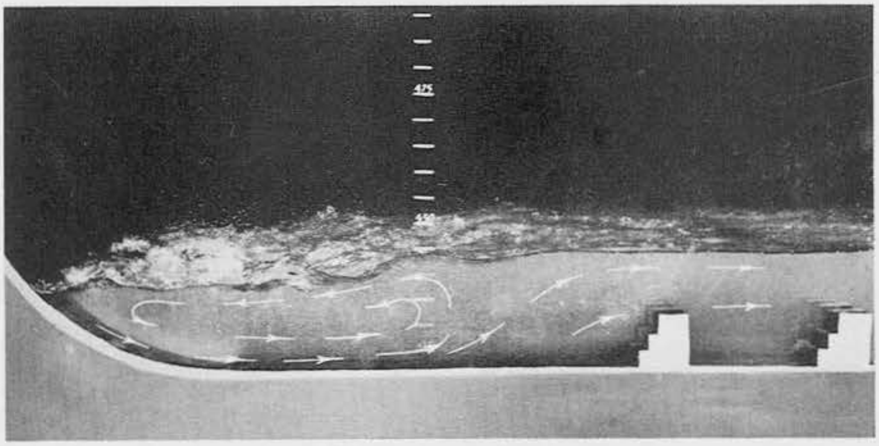


Discharge 50,000 cfs; TW elev 448.3; pool elev 540.86

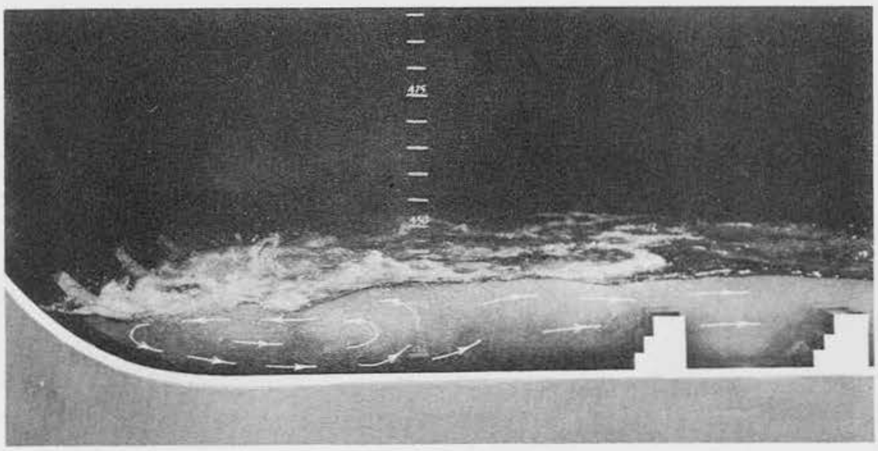
PHOTOGRAPH 3. Flow conditions -- type 1 apron and various spillway discharges



16 conduits
Discharge 46,400 cfs; TW elev 448.0; pool elev 571.0

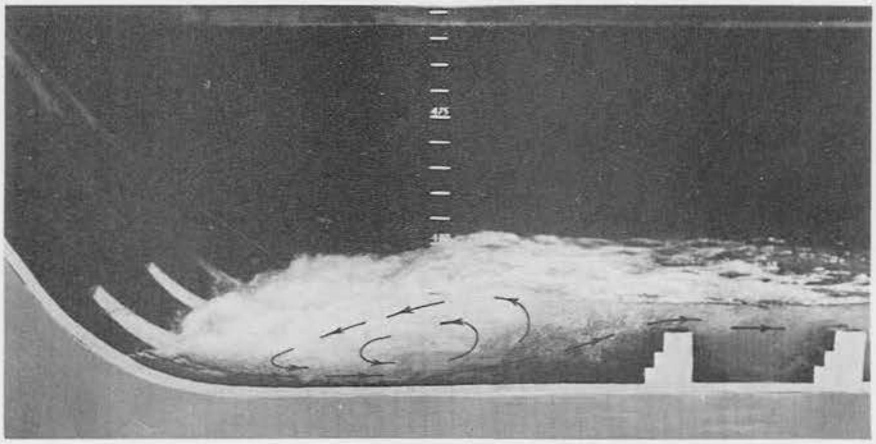


12 conduits
Discharge 36,000 cfs; TW elev 444.4; pool elev 571.0

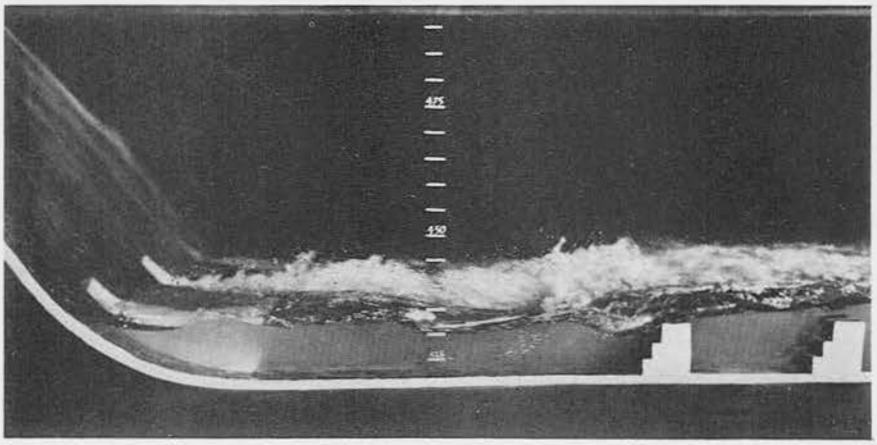


8 conduits
Discharge 20,000 cfs; TW elev 438.4; pool elev 528.9

PHOTOGRAPH 4. Flow conditions -- type 1 apron and various conduit discharges

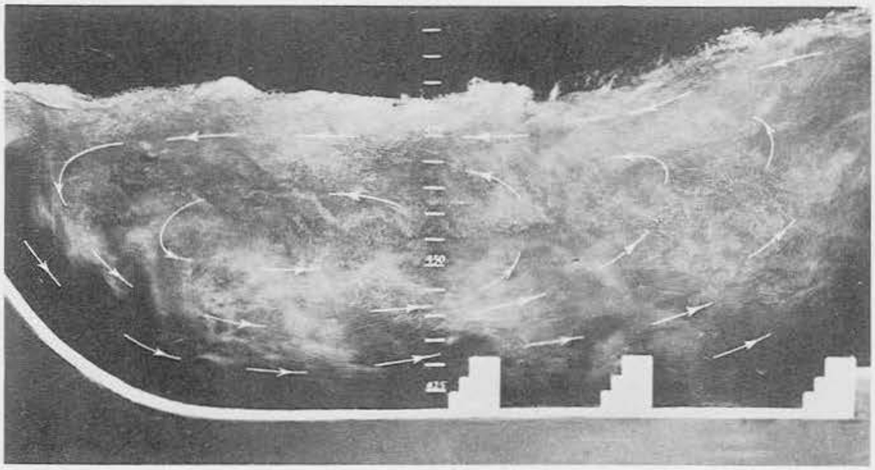


3 conduits
Discharge 9,000 cfs; TW controlled by end sill
Pool elev 571.0

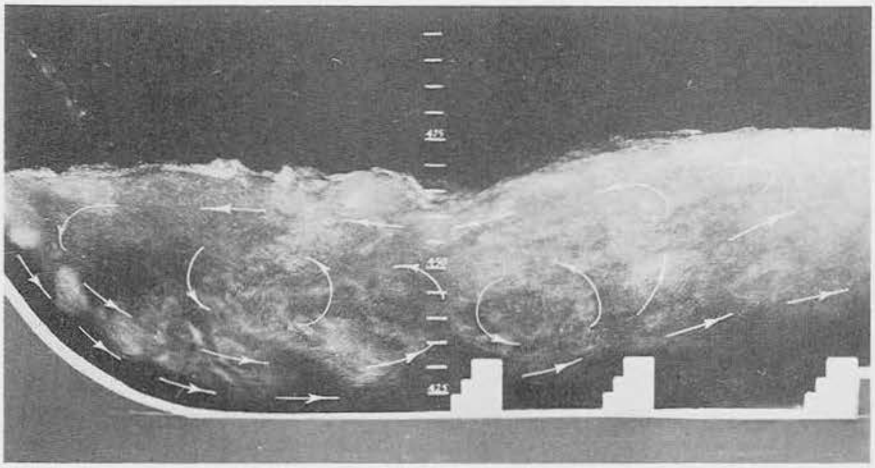


1 conduit
Discharge 3,000 cfs; TW controlled by end sill
Pool elev 571.0

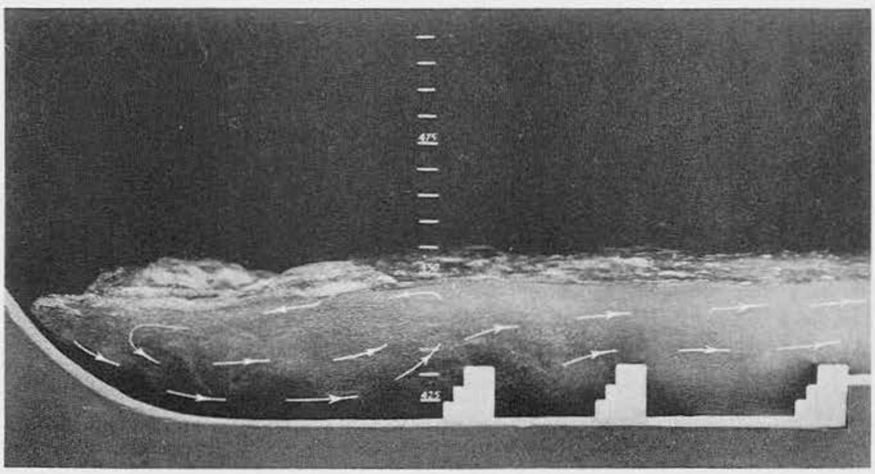
PHOTOGRAPH 5. Flow conditions -- type 1 apron and various conduit discharges



Discharge 660,000 cfs; TW elev 497.6; pool elev 572.12

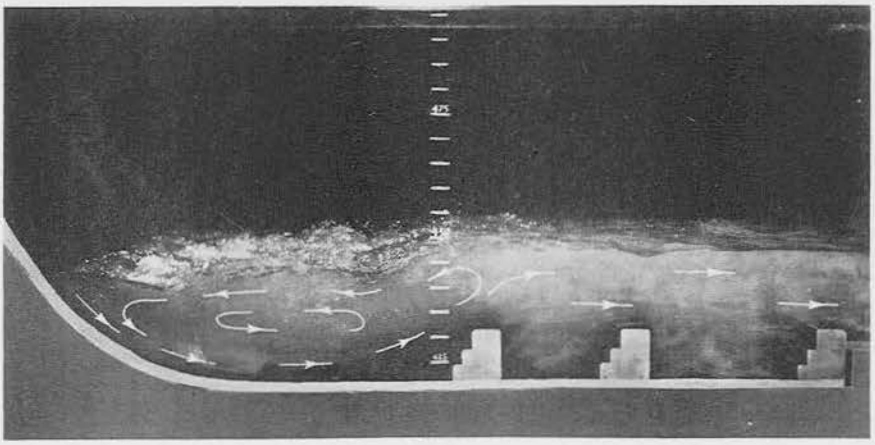


Discharge 250,000 cfs; TW elev 475.4; pool elev 555.03

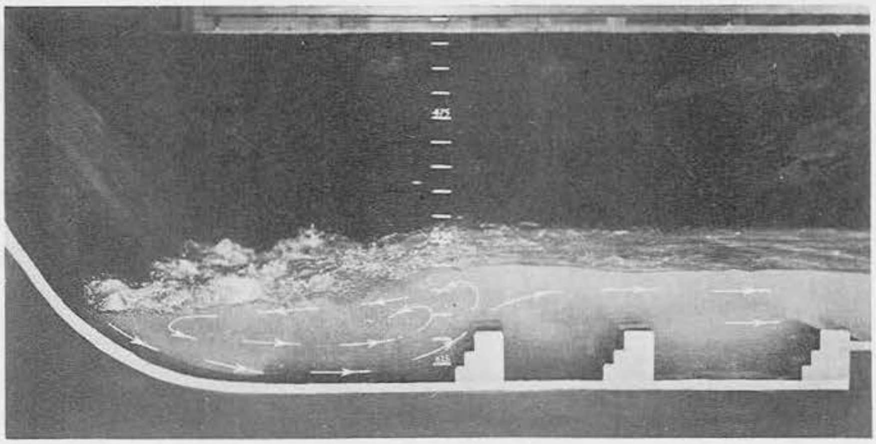


Discharge 50,000 cfs; TW elev 448.3; pool elev 540.86

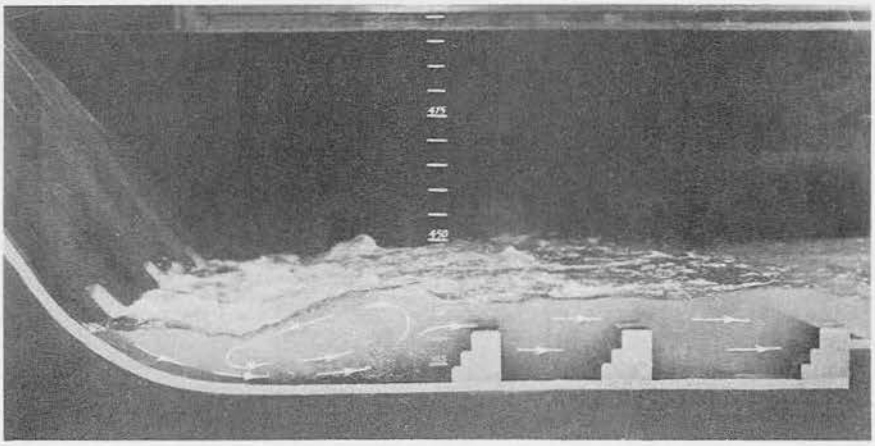
PHOTOGRAPH 6. Flow conditions -- type 2 apron and various spillway discharges



16 conduits
Discharge 46,400 cfs; TW elev 448.0; pool elev 571.0

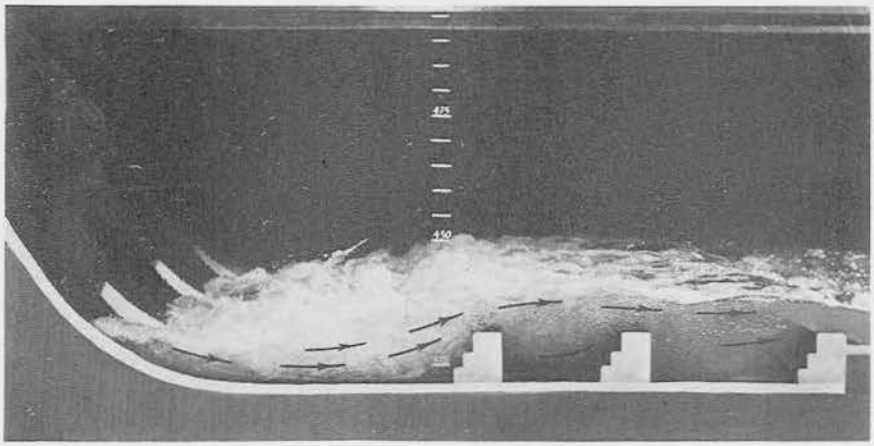


12 conduits
Discharge 36,000 cfs; TW elev 444.4; pool elev 571.0

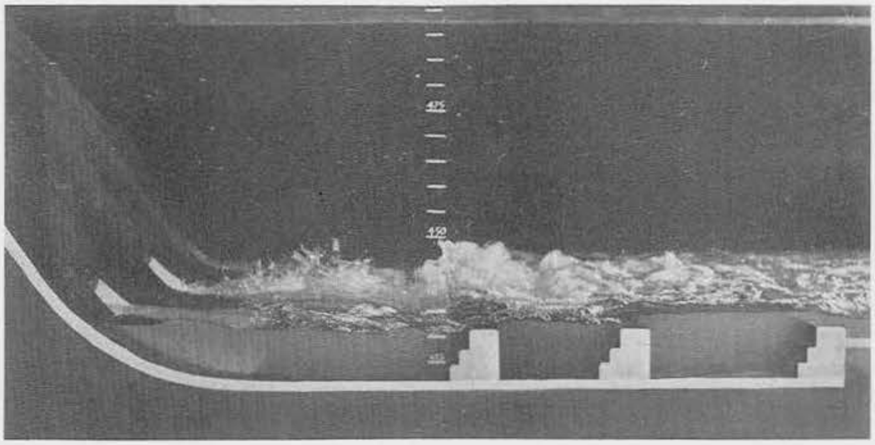


8 conduits
Discharge 20,000 cfs; TW elev 438.4; pool elev 528.9

PHOTOGRAPH 7. Flow conditions -- type 2 apron and various conduit discharges

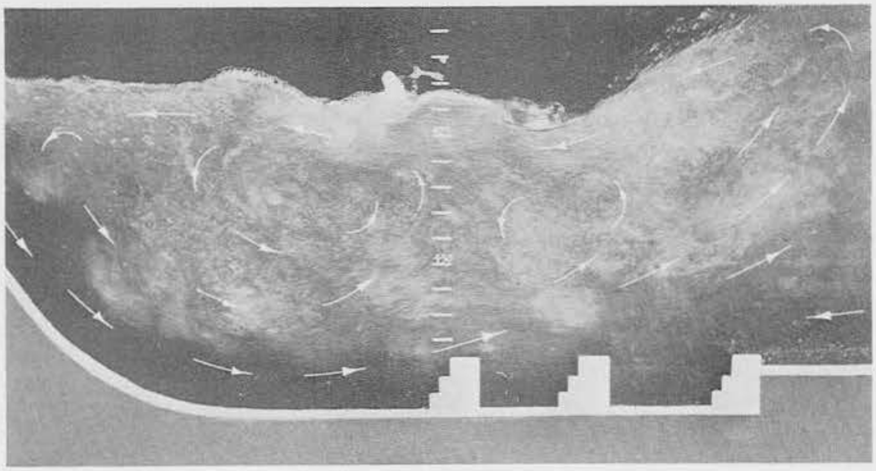


3 conduits
Discharge 9,000 cfs; TW controlled by end sill
Pool elev 571.0

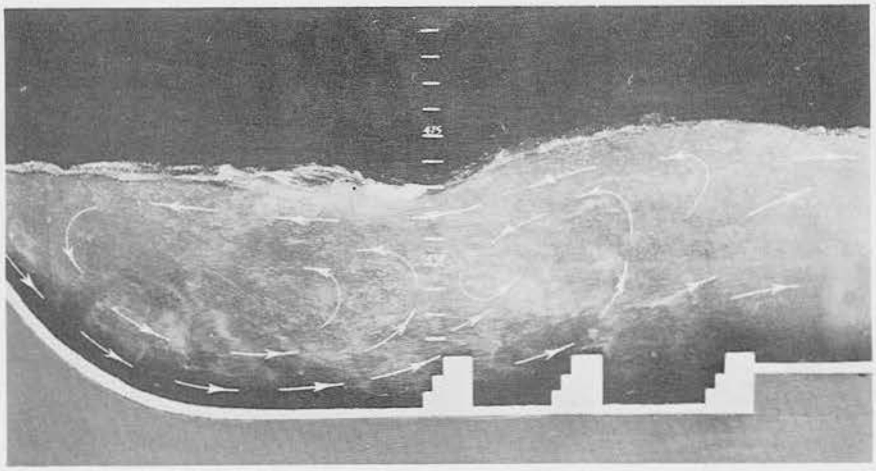


1 conduit
Discharge 3,000 cfs; TW controlled by end sill
Pool elev 571.0

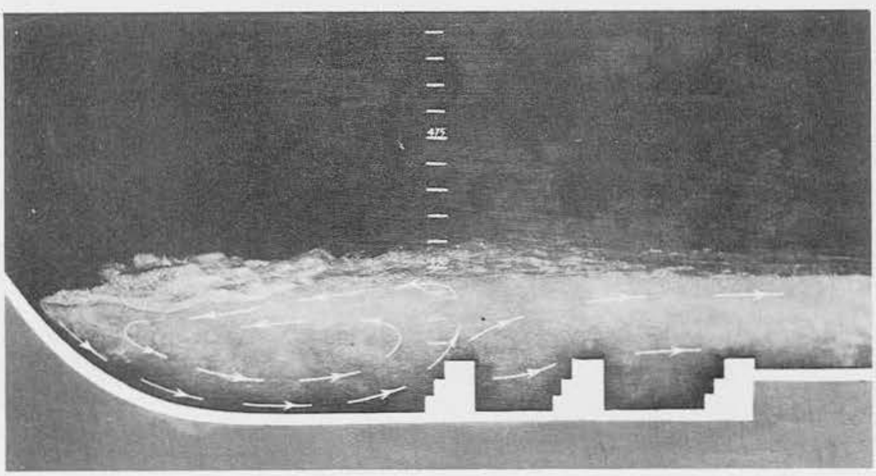
PHOTOGRAPH 8. Flow conditions -- type 2 apron and various conduit discharges



Discharge 660,000 cfs; TW elev 497.6; pool elev 572.12

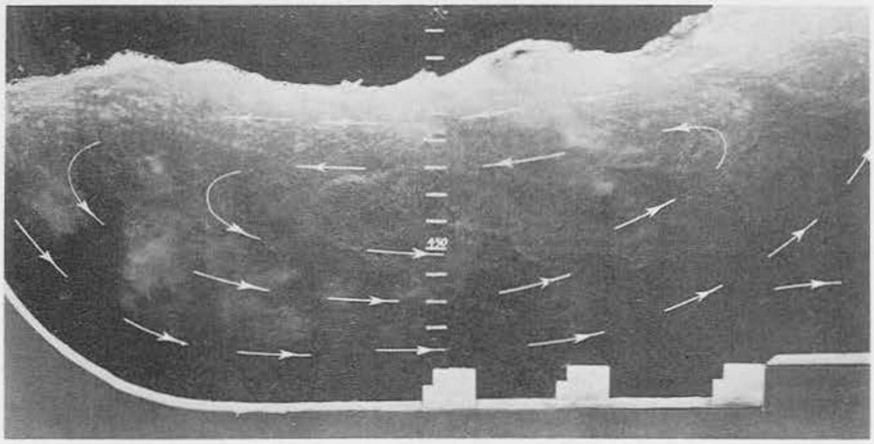


Discharge 250,000 cfs; TW elev 475.4; pool elev 555.03

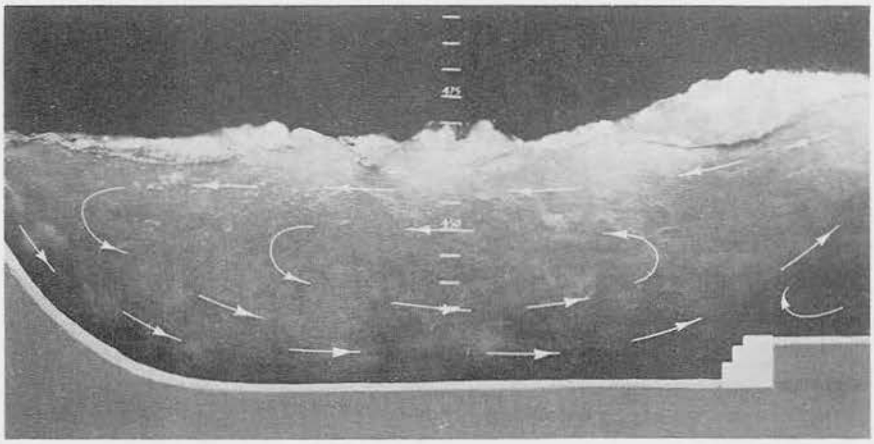


Discharge 50,000 cfs; TW elev 448.3; pool elev 540.86

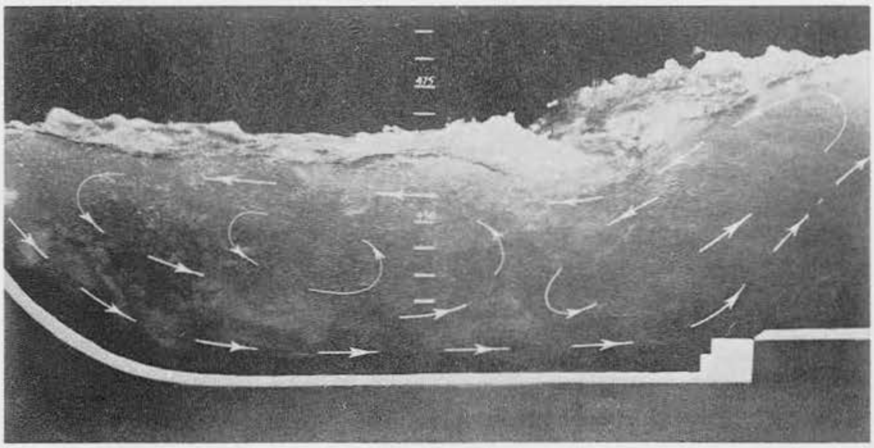
PHOTOGRAPH 9. Flow conditions -- type 3 apron and various spillway discharges



6-ft end sill and baffles
Discharge 660,000 cfs; TW elev 497.6; pool elev 572.12

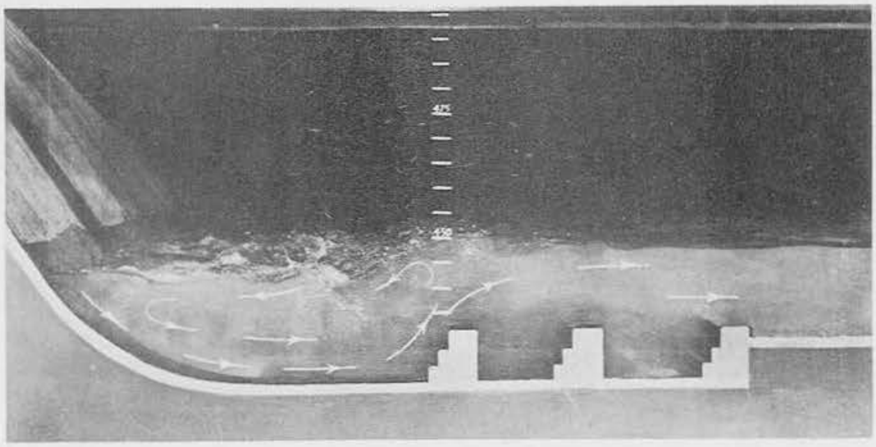


8-ft end sill, no baffles
Discharge 250,000 cfs; TW elev 475.4; pool elev 555.03

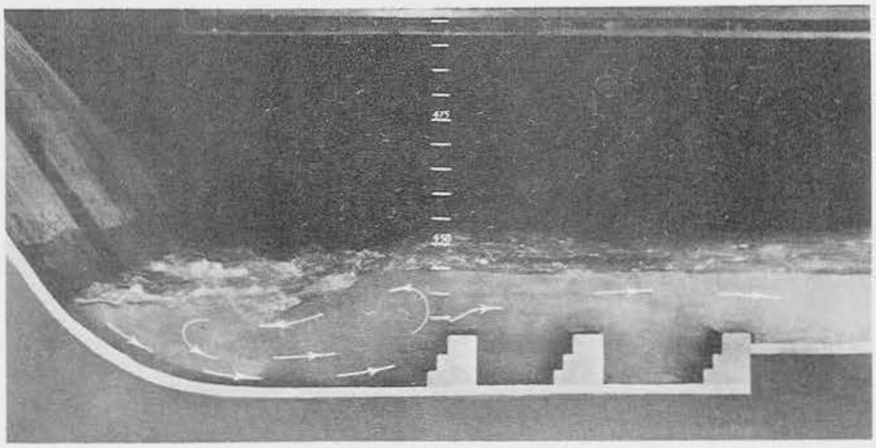


6-ft end sill, no baffles
Discharge 250,000 cfs; TW elev 475.4; pool elev 555.03

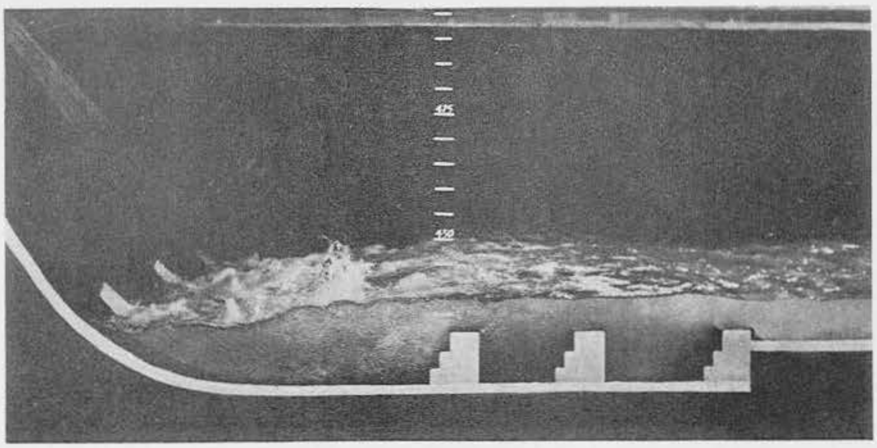
PHOTOGRAPH 10. Flow conditions -- type 3 apron with and without baffle piers, with end-sill height varied, and with various spillway discharges



16 conduits
Discharge 46,400 cfs; TW elev 448.0; pool elev 571.0

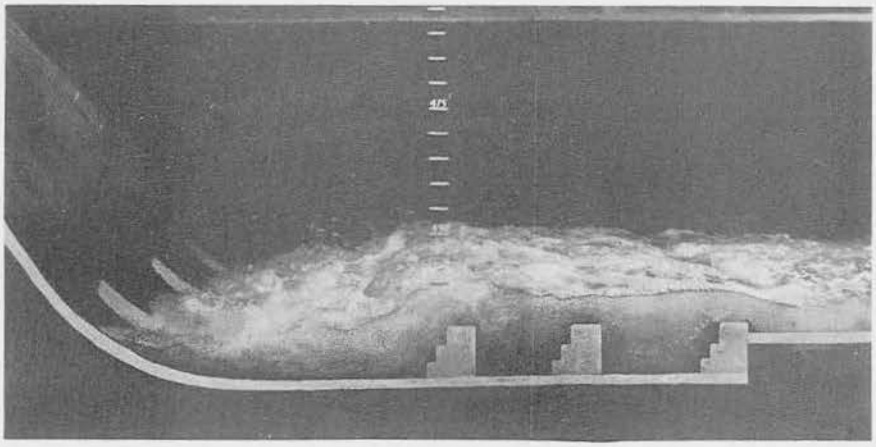


12 conduits
Discharge 36,000 cfs; TW elev 444.4; pool elev 571.0

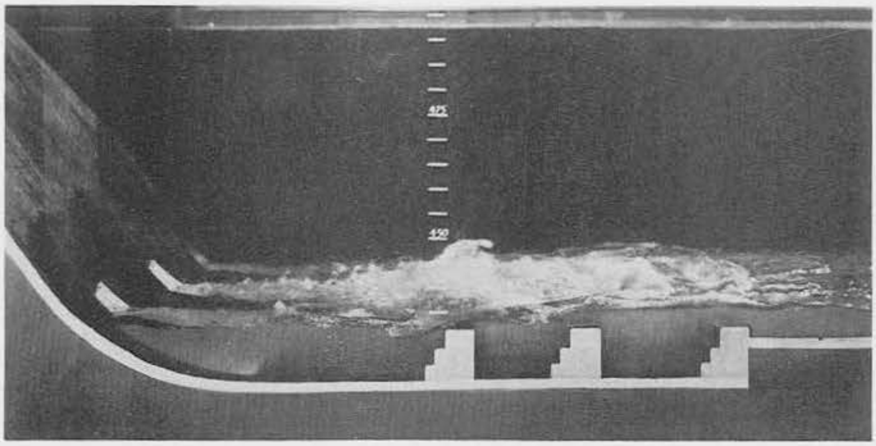


8 conduits
Discharge 20,000 cfs; TW elev 438.4; pool elev 528.9

PHOTOGRAPH 11. Flow conditions -- type 3 apron and various conduit discharges



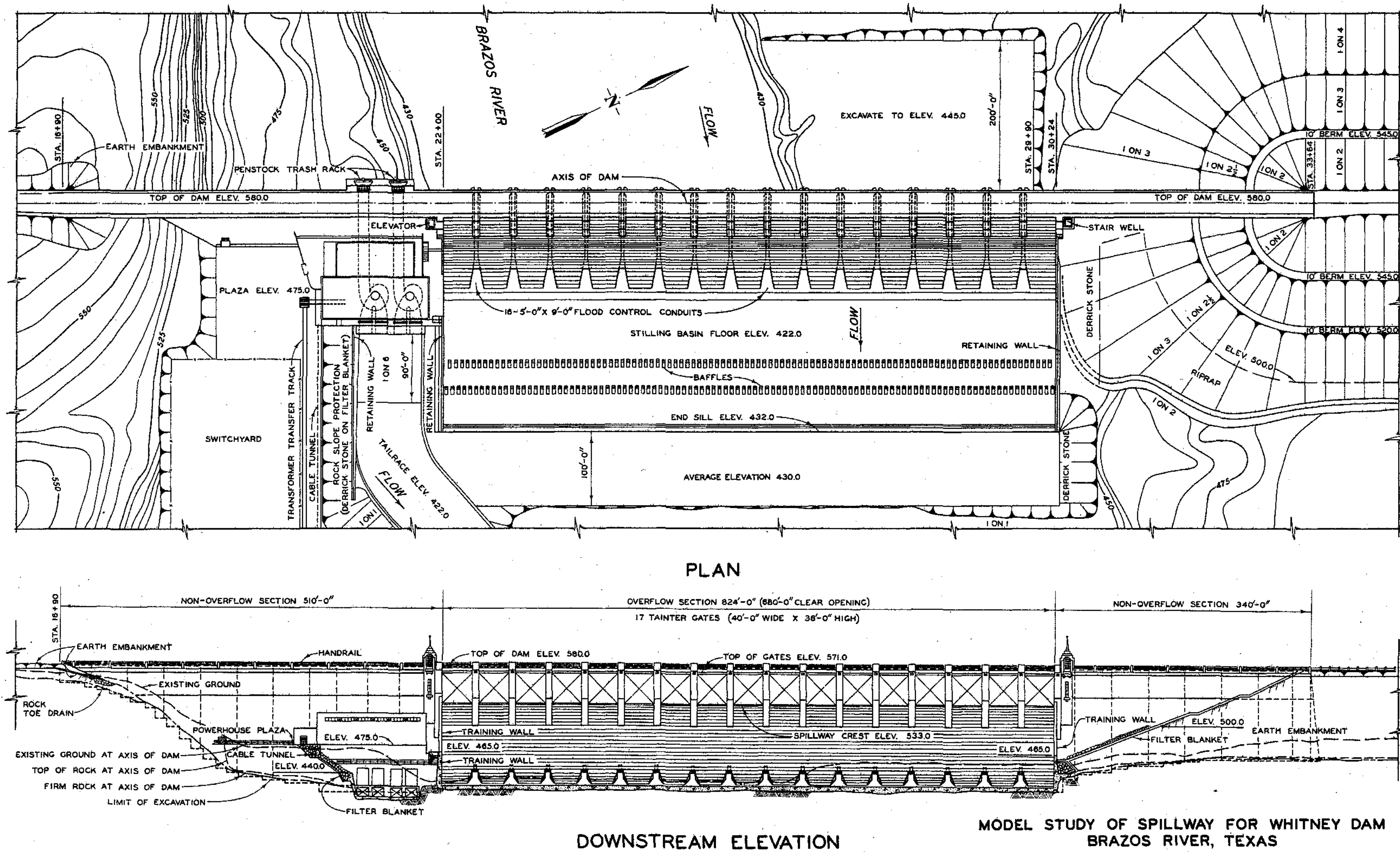
3 conduits
Discharge 9,000 cfs; TW controlled by end sill
Pool elev 571.0



1 conduit
Discharge 3,000 cfs; TW controlled by end sill
Pool elev 571.0

PHOTOGRAPH 12. Flow conditions -- type 3 apron and various conduit discharges

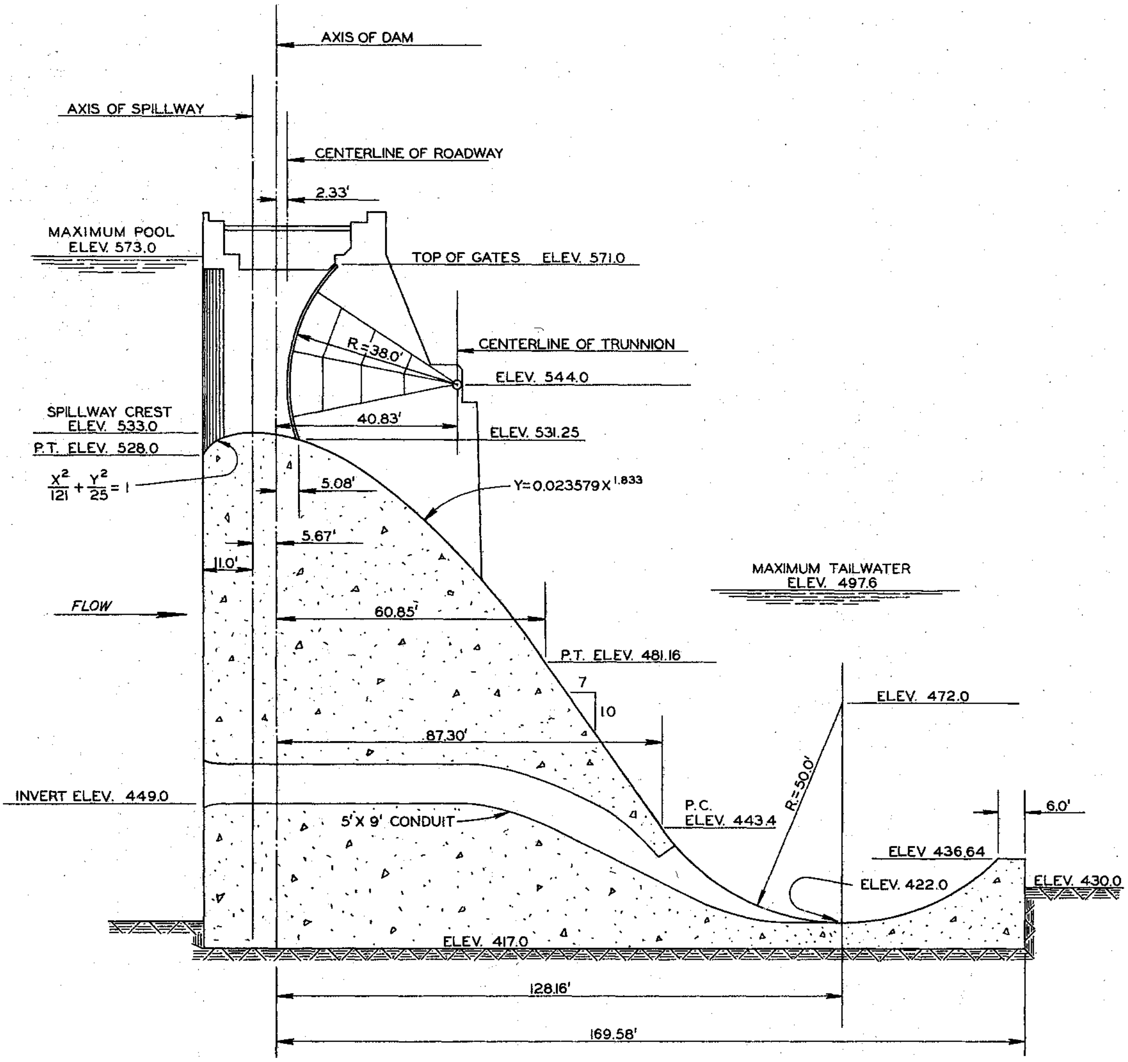
PLATES



MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

SPILLWAY
PLAN AND ELEVATION
TYPE 1 APRON - ORIGINAL DESIGN

PLATE 1



TYPICAL SPILLWAY SECTION

SCALE
20 0 20 40 60 FT.

NOTE: DESIGN HEAD ON SPILLWAY CREST 40.0 FT.

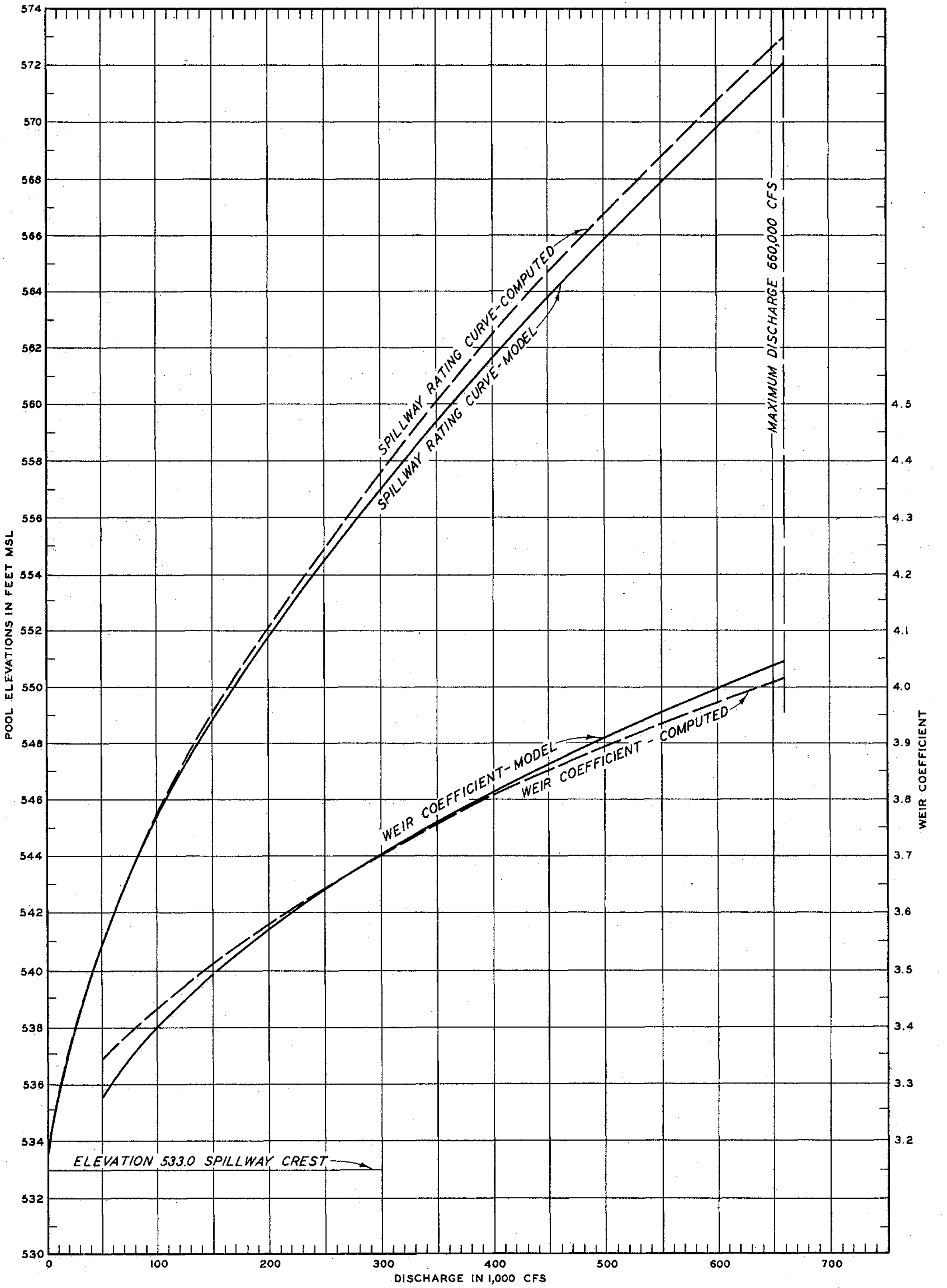
CONDUIT IS LOCATED ALONG CENTERLINE OF PIER.

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM

BRAZOS RIVER, TEXAS

SPILLWAY AND BUCKET

ORIGINAL DESIGN



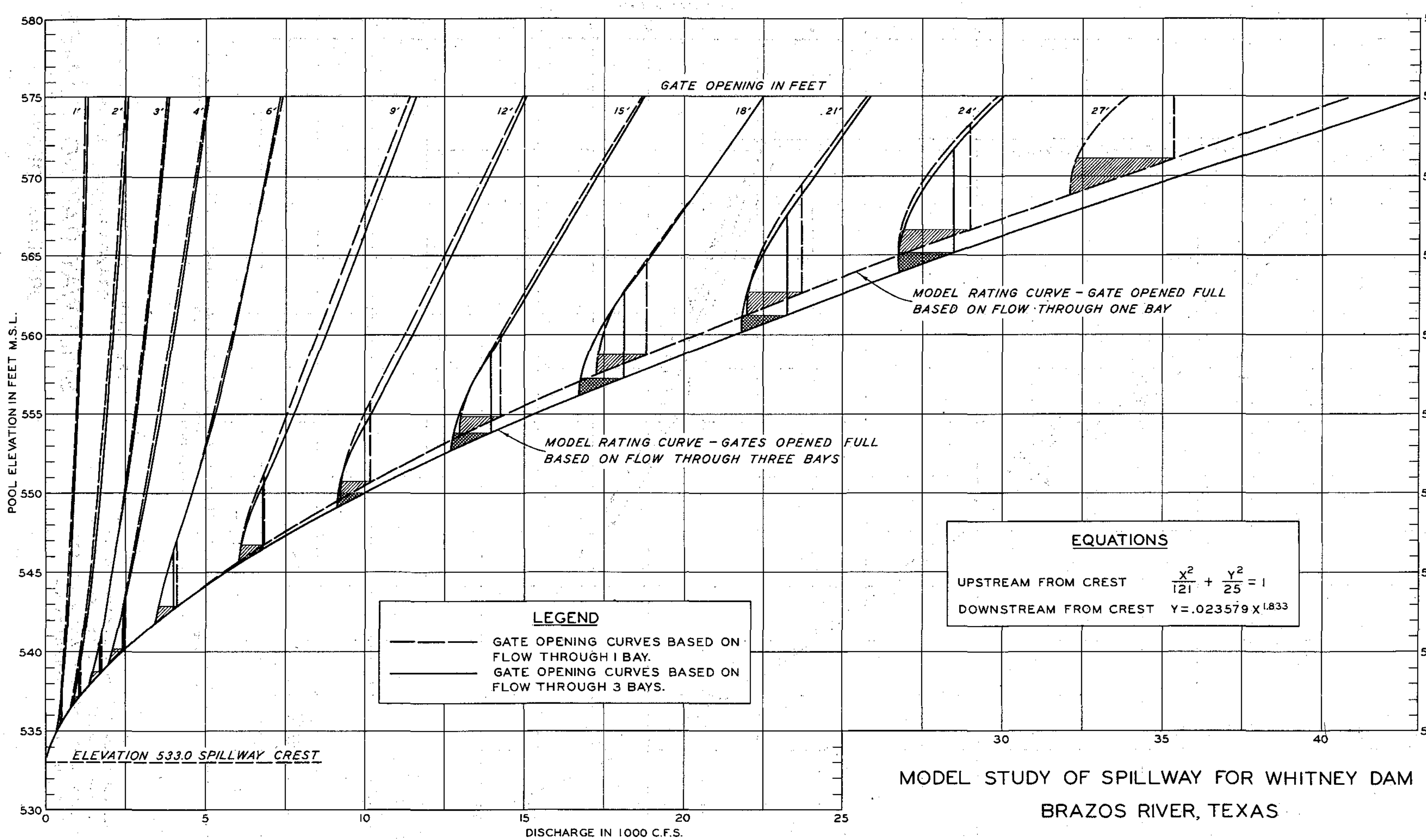
NOTE: MODEL COEFFICIENT "C" COMPUTED FROM FORMULA
$Q=C(L-KNH)H^{3/2}$ WITH "K" ASSUMED = 0.015
COMPUTED COEFFICIENT "C" COMPUTED FROM FORMULA
$Q=C(L-KNH)H^{3/2}$ WITH "K" ASSUMED = 0.020

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

SPILLWAY RATING CURVES

ORIGINAL DESIGN

PLATE 4



NOTE: GATE OPENING IS THE VERTICAL DISTANCE IN FEET BETWEEN THE GATE LIP AND THE GATE SEAT.

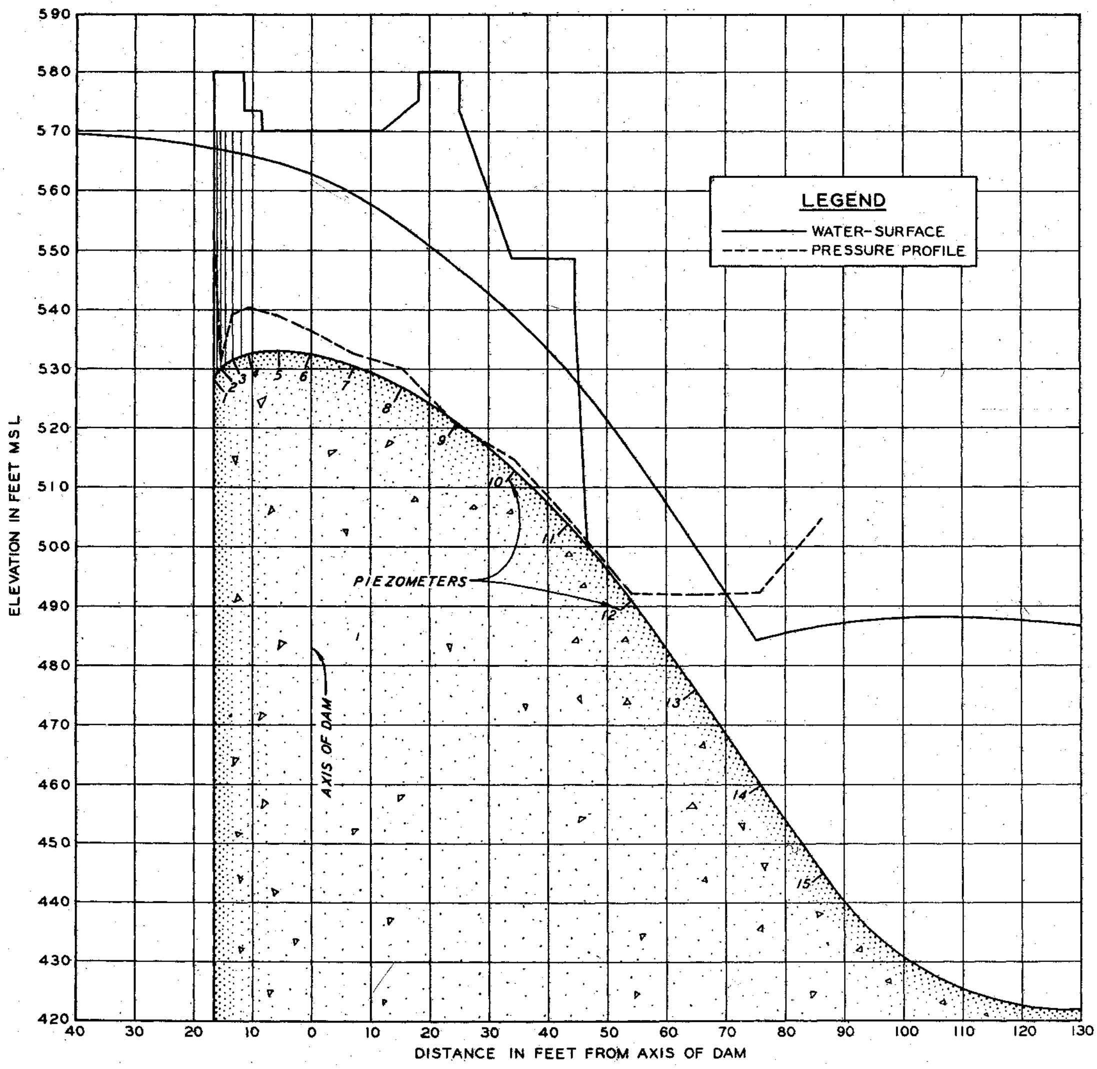
SHADED AREAS INDICATE DISCHARGE RANGE IN WHICH POOL ELEVATION IS DEPENDENT UPON A RISING OR FALLING RESERVOIR.

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM

BRAZOS RIVER, TEXAS

RATING CURVE FOR ONE GATE

ORIGINAL DESIGN



PIEZ NO.	PIEZ ZERO	PIEZ READING	PRESSURE
1	528.0	552.5	24.5
2	530.0	531.5	1.5
3	531.5	539.5	8.0
4	532.5	540.5	8.0
5	533.0	539.0	6.0
6	532.5	536.5	4.0
7	530.5	532.5	2.0
8	527.0	530.5	3.5
9	521.0	520.5	-0.5
10	513.0	515.0	2.0
11	504.0	505.0	1.0
12	491.0	492.0	1.0
13	476.0	492.0	16.0
14	460.0	492.5	32.5
15	445.0	504.5	59.5

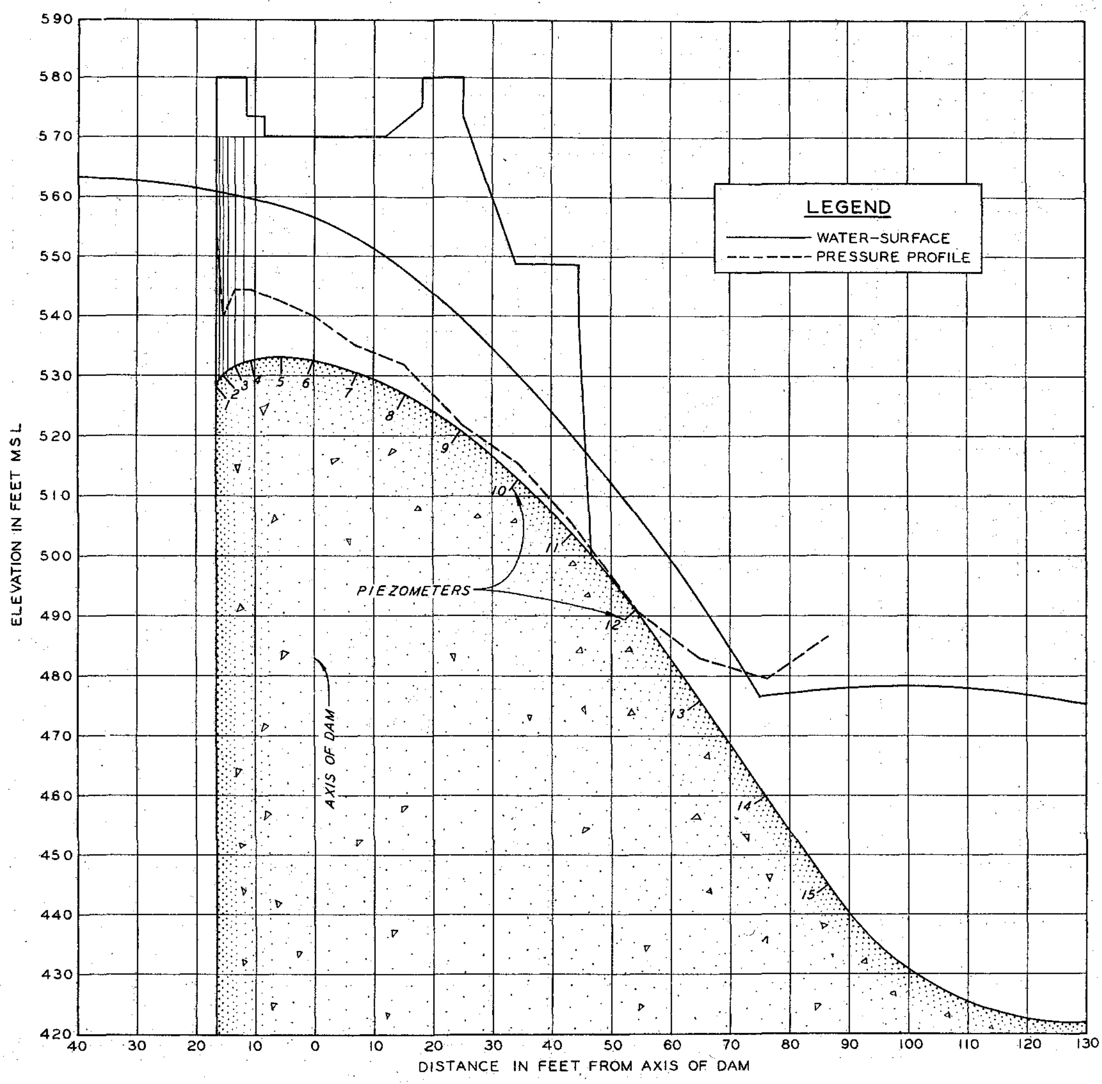
PRESSURE DATA

NOTE: PRESSURES ARE RECORDED IN FEET OF WATER IN PROTOTYPE TO THE NEAREST 0.5 FOOT

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

WATER-SURFACE AND PRESSURE PROFILES

DISCHARGE	660,000 CFS
POOL ELEV	572.12
TAILWATER	497.60



PIEZ NO.	PIEZ ZERO	PIEZ READING	PRESSURE
1	528.0	553.5	25.5
2	530.0	540.0	10.0
3	531.5	544.5	13.0
4	532.5	544.5	12.0
5	533.0	542.5	9.5
6	532.5	540.0	7.5
7	530.5	535.0	4.5
8	527.0	532.0	5.0
9	521.0	522.0	1.0
10	513.0	515.5	2.5
11	504.0	505.5	1.5
12	491.0	491.0	0.0
13	476.0	483.0	7.0
14	460.0	479.5	19.5
15	445.0	486.5	41.5

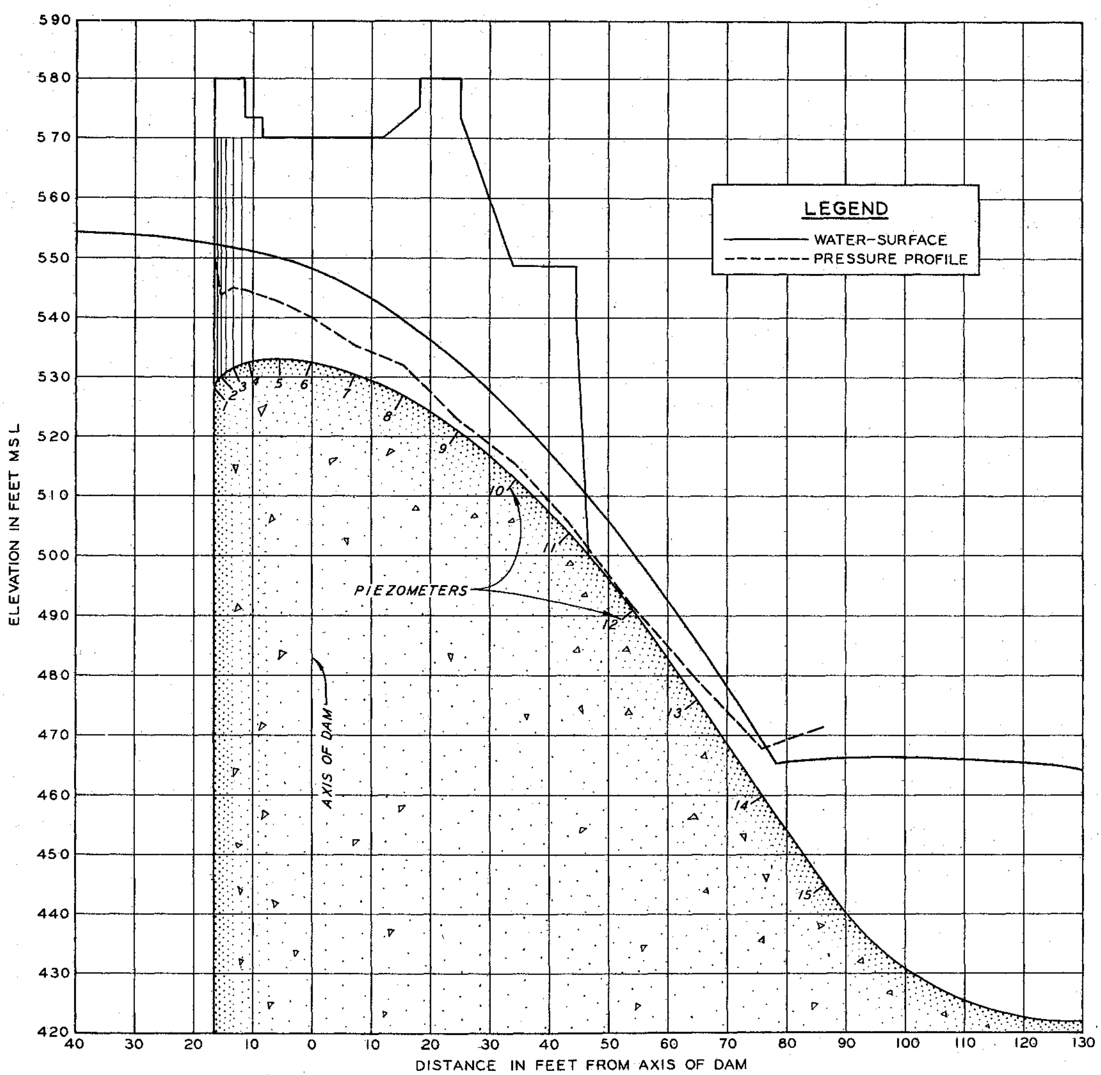
PRESSURE DATA

NOTE: PRESSURES ARE RECORDED IN FEET OF WATER IN PROTOTYPE TO THE NEAREST 0.5 FOOT

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

WATER-SURFACE AND PRESSURE PROFILES

DISCHARGE	450,000 CFS
POOL ELEV	564.19
TAILWATER ELEV	488.20



PIEZ NO.	PIEZ ZERO	PIEZ READING	PRESSURE
1	528.0	550.0	22.0
2	530.0	544.0	14.0
3	531.5	545.0	13.5
4	532.5	544.5	12.0
5	533.0	542.5	9.5
6	532.5	540.0	7.5
7	530.5	535.5	5.0
8	527.0	532.0	5.0
9	521.0	523.0	2.0
10	513.0	515.5	2.5
11	504.0	505.5	1.5
12	491.0	491.5	0.5
13	476.0	479.5	3.5
14	460.0	468.0	8.0
15	445.0	471.5	26.5

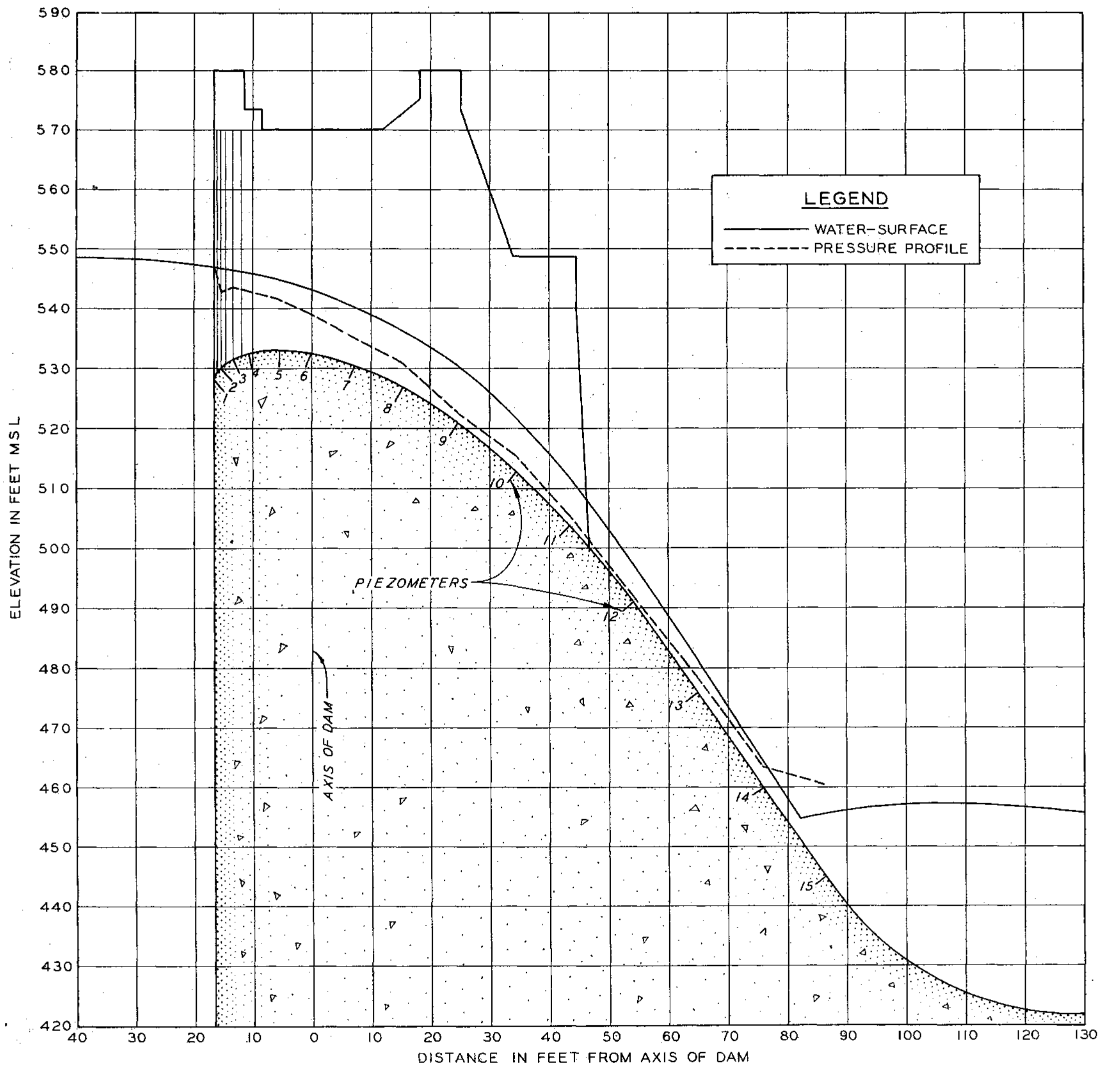
PRESSURE DATA

NOTE: PRESSURES ARE RECORDED IN FEET OF WATER IN PROTOTYPE TO THE NEAREST 0.5 FOOT

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

WATER-SURFACE AND PRESSURE PROFILES

DISCHARGE	250,000 CFS
POOL ELEV	555.03
TAILWATER ELEV	475.35



PIEZ NO.	PIEZ ZERO	PIEZ READING	PRESSURE
1	528.0	547.0	19.0
2	530.0	543.0	13.0
3	531.5	543.5	12.0
4	532.5	543.0	10.5
5	533.0	541.5	8.5
6	532.5	539.0	6.5
7	530.5	535.0	4.5
8	527.0	531.0	4.0
9	521.0	522.5	1.5
10	513.0	515.5	2.5
11	504.0	505.5	1.5
12	491.0	491.5	0.5
13	476.0	478.5	2.5
14	460.0	463.5	3.5
15	445.0	460.5	15.5

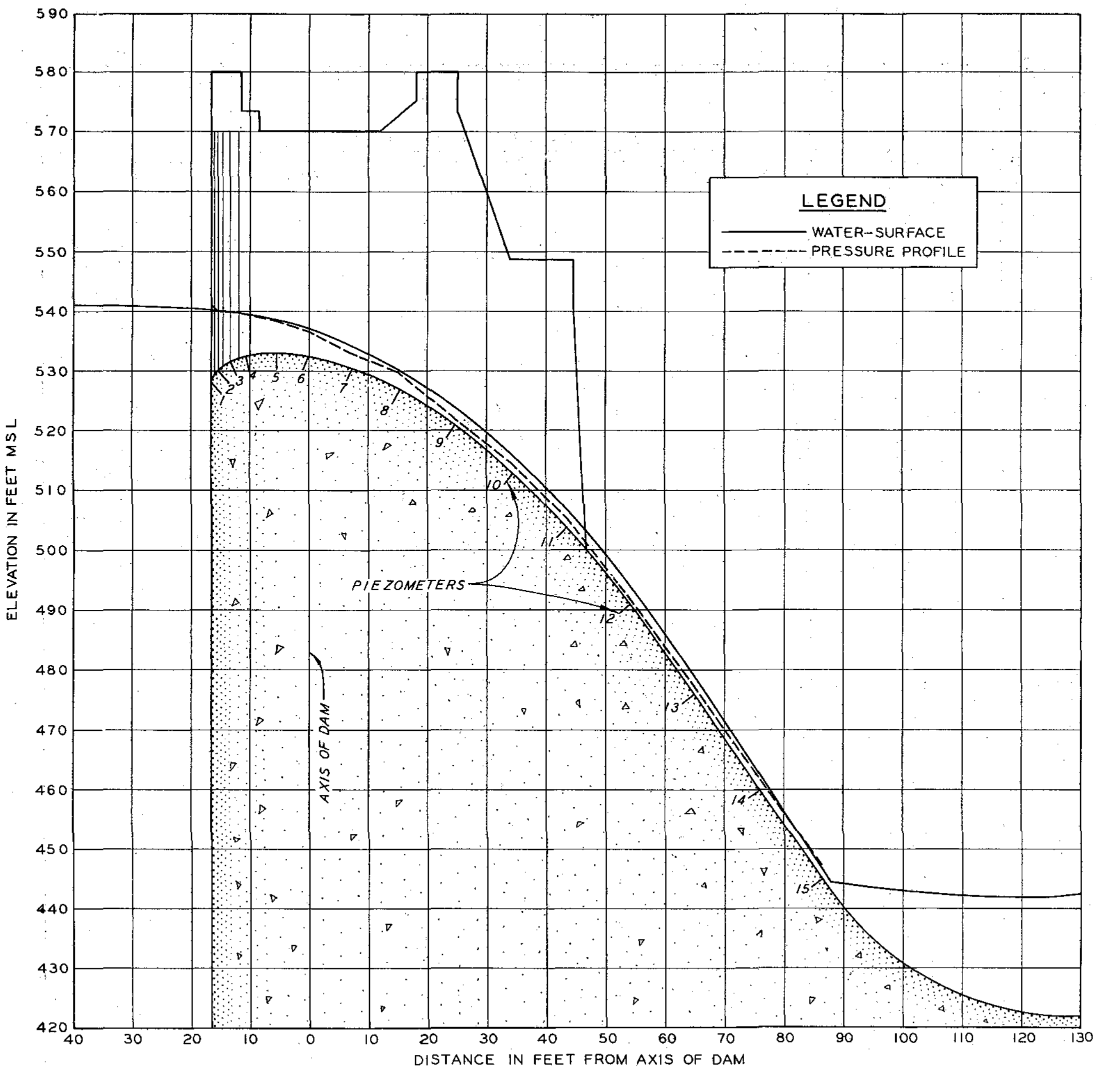
PRESSURE DATA

NOTE: PRESSURES ARE RECORDED IN FEET OF WATER IN PROTOTYPE TO THE NEAREST 0.5 FOOT

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

WATER-SURFACE AND PRESSURE PROFILES

DISCHARGE	150,000 CFS
POOL ELEV	548.93
TAILWATER ELEV	464.85



PIEZ NO.	PIEZ ZERO	PIEZ READING	PRESSURE
1	528.0	541.0	13.0
2	530.0	540.0	10.0
3	531.5	540.0	8.5
4	532.5	539.5	7.0
5	533.0	538.5	5.5
6	532.5	536.5	4.0
7	530.5	533.0	2.5
8	527.0	529.5	2.5
9	521.0	522.0	1.0
10	513.0	514.5	1.5
11	504.0	505.5	1.5
12	491.0	491.5	0.5
13	476.0	477.5	1.5
14	460.0	462.0	2.0
15	445.0	447.0	2.0

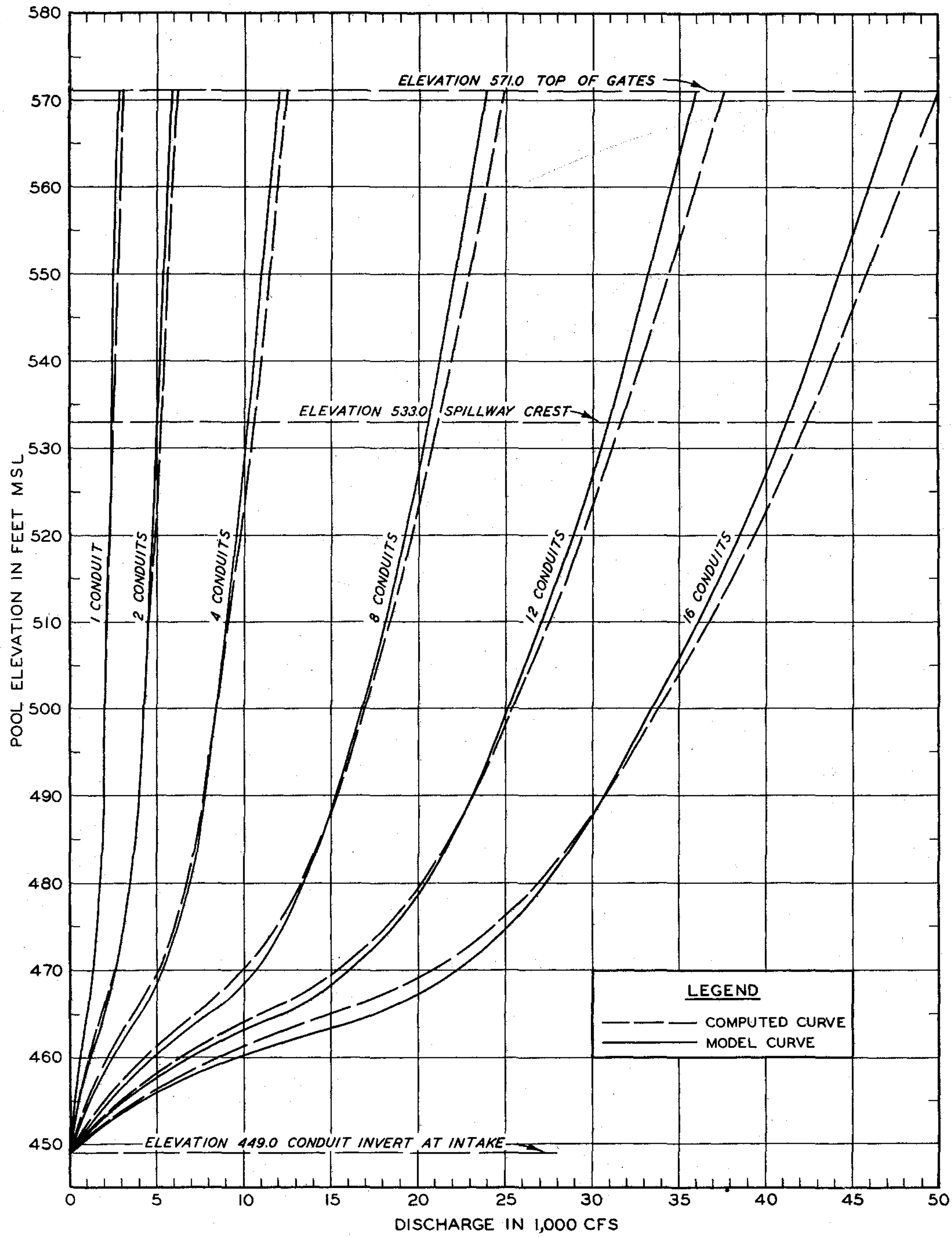
PRESSURE DATA

NOTE: PRESSURES ARE RECORDED IN FEET OF WATER IN PROTOTYPE TO THE NEAREST 0.5 FOOT

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

WATER-SURFACE AND PRESSURE PROFILES

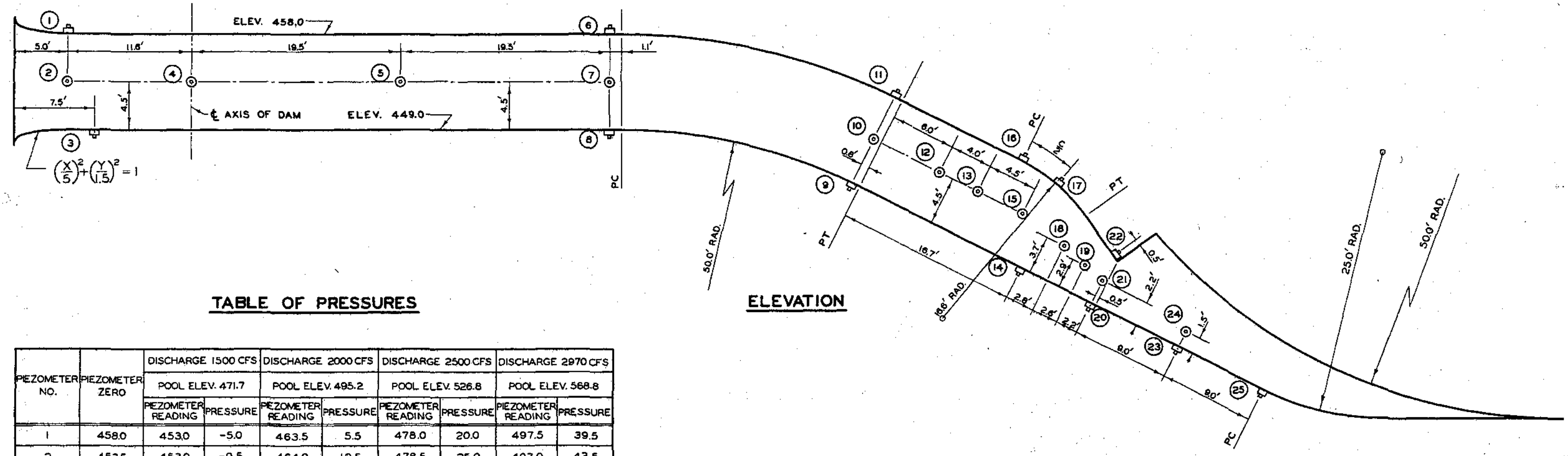
DISCHARGE	50,000 CFS
POOL ELEV	540.86
TAILWATER ELEV	448.3



NOTE: FOR COMPARISON PURPOSES, NO TAILWATER WAS SET ON THESE CALIBRATION TESTS.

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

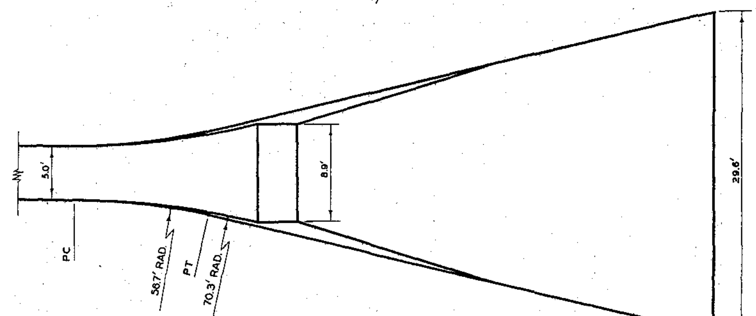
RATING CURVES FOR FLOOD CONTROL CONDUITS



ELEVATION

TABLE OF PRESSURES

PIEZOMETER NO.	PIEZOMETER ZERO	DISCHARGE 1500 CFS		DISCHARGE 2000 CFS		DISCHARGE 2500 CFS		DISCHARGE 2970 CFS	
		POOL ELEV. 471.7		POOL ELEV. 495.2		POOL ELEV. 526.8		POOL ELEV. 568.8	
		PIEZOMETER READING	PRESSURE	PIEZOMETER READING	PRESSURE	PIEZOMETER READING	PRESSURE	PIEZOMETER READING	PRESSURE
1	458.0	453.0	-5.0	463.5	5.5	478.0	20.0	497.5	39.5
2	453.5	453.0	-0.5	464.0	10.5	478.5	25.0	497.0	43.5
3	449.0	453.5	4.5	464.0	15.0	479.5	30.5	499.0	50.0
4	453.5	452.5	-1.0	462.5	9.0	476.5	23.0	494.5	41.0
5	453.5	450.5	-3.0	460.0	6.5	472.5	19.0	489.0	35.5
6	458.0	451.5	-6.5	461.0	3.0	474.5	16.5	492.0	34.0
7	453.5	449.0	-4.5	457.0	3.5	468.0	14.5	482.5	29.0
8	449.0	448.0	-1.0	455.0	6.0	465.0	16.0	478.0	29.0
9	443.9	447.0	3.1	453.0	9.1	462.0	18.1	473.5	29.6
10	447.9	447.0	-0.9	454.0	6.1	463.5	15.6	475.0	27.1
11	451.9	449.0	-2.9	455.5	3.6	466.0	14.1	479.0	27.1
12	444.7	447.0	2.3	454.0	9.3	463.0	18.3	475.5	30.8
13	443.0	448.5	5.5	456.0	13.0	466.5	23.5	481.0	38.0
14	436.1	449.5	13.4	458.0	21.9	470.0	33.9	485.5	49.4
15	441.1	451.0	9.9	460.5	19.4	473.0	31.9	490.0	48.9
16	446.1	455.5	9.4	465.5	19.4	481.5	35.4	500.5	54.4
17	444.0	456.5	12.5	471.0	27.0	489.0	45.0	514.0	70.0
18	438.1	450.0	11.9	458.5	20.4	470.5	32.4	487.0	48.9
19	436.3	446.0	9.7	452.0	15.7	461.0	24.7	472.0	35.7
20	432.6	443.5	10.9	448.5	15.9	455.0	22.4	465.0	32.4
21	434.6	441.0	6.4	444.5	9.9	449.0	14.4	454.0	19.4
22	436.9	438.0	1.1	439.0	2.1	441.5	4.6	440.0	3.9
23	428.6	436.0	7.4	435.5	6.9	434.0	5.4	433.5	4.9
24	430.0	436.0	6.0	435.0	5.0	435.0	5.0	435.5	5.5
25	424.6	439.0	14.4	441.0	16.4	442.0	17.4	443.0	18.4



PLAN OF OUTLET PORTAL

NOTES: ALL TOP AND BOTTOM PIEZOMETERS ARE ON CENTERLINE OF CONDUIT.

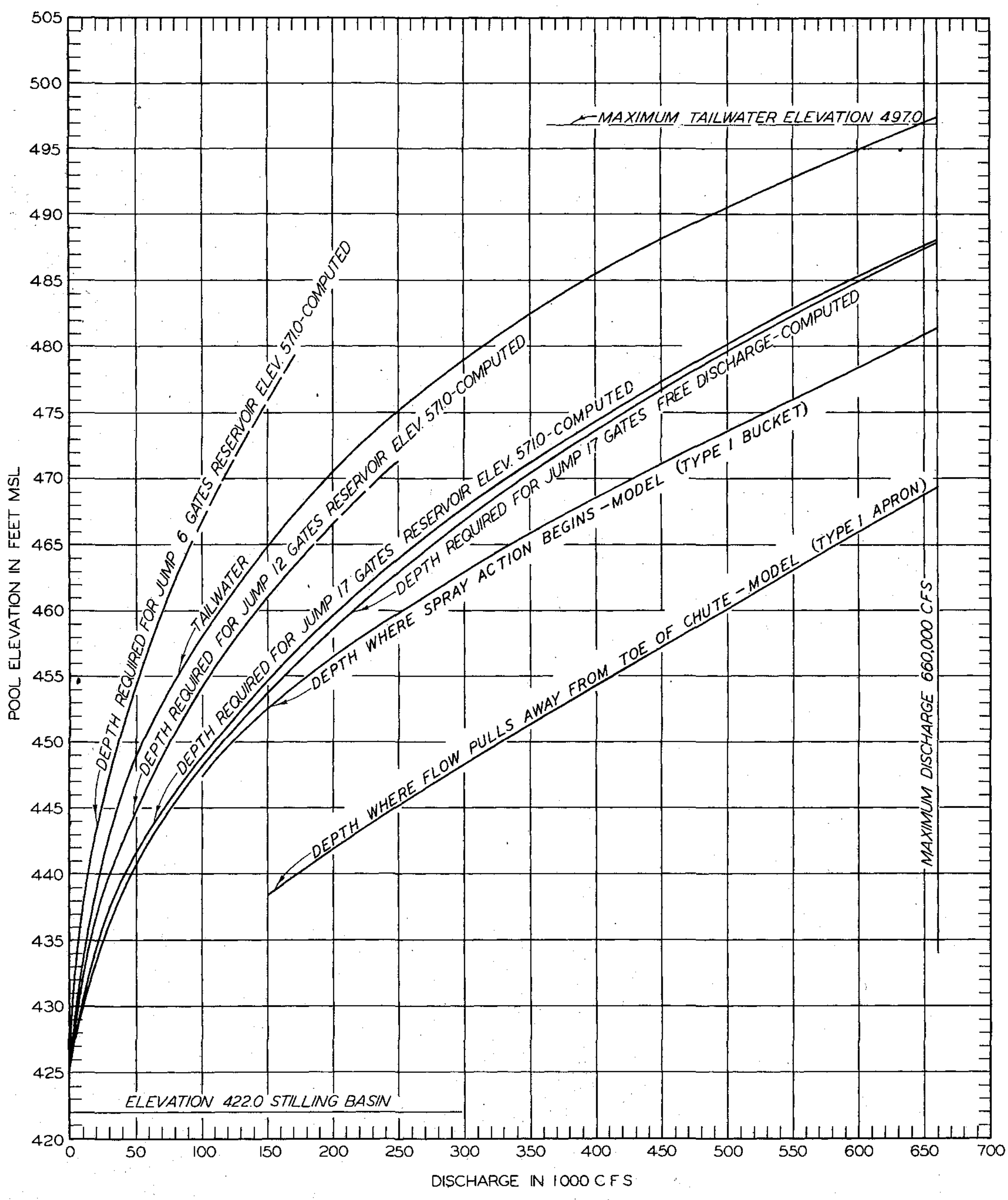
DISCHARGES BASED ON FLOW THROUGH ONE CONDUIT.

PRESSURES ARE RECORDED IN FEET OF WATER IN PROTOTYPE.

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

PIEZOMETER LOCATIONS AND PRESSURE MEASUREMENTS

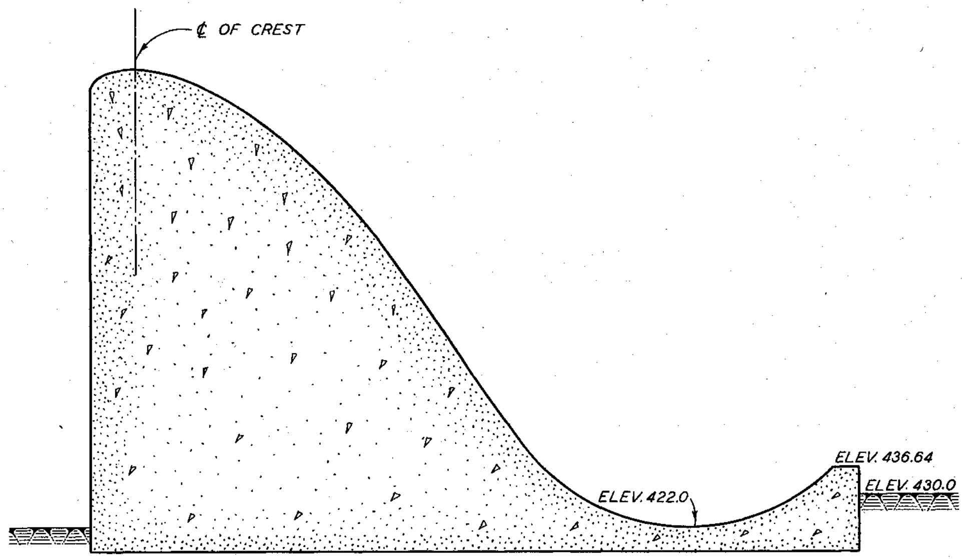
SCALE
5 0 5 10 15FT.



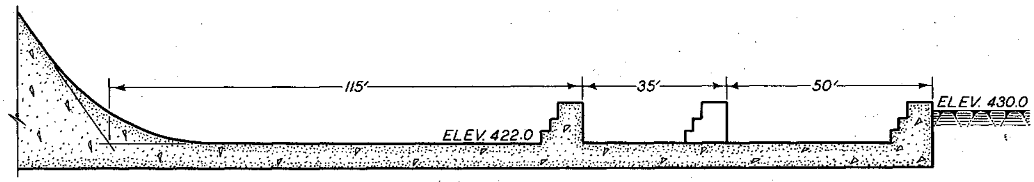
NOTE: TAILWATER CURVE ASSUMES SCOUR TO BEDROCK IN CHANNEL.

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

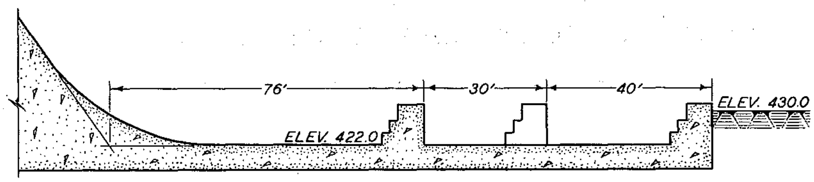
TAILWATER AND JUMP CURVES



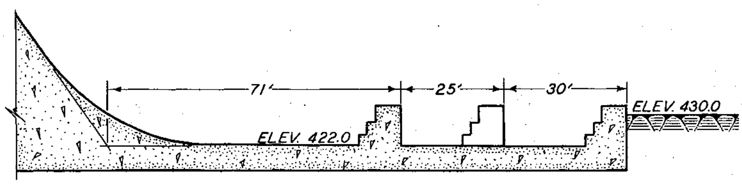
TYPE I BUCKET - ORIGINAL DESIGN



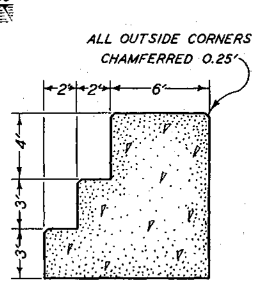
TYPE I APRON - ORIGINAL DESIGN



TYPE 2 APRON



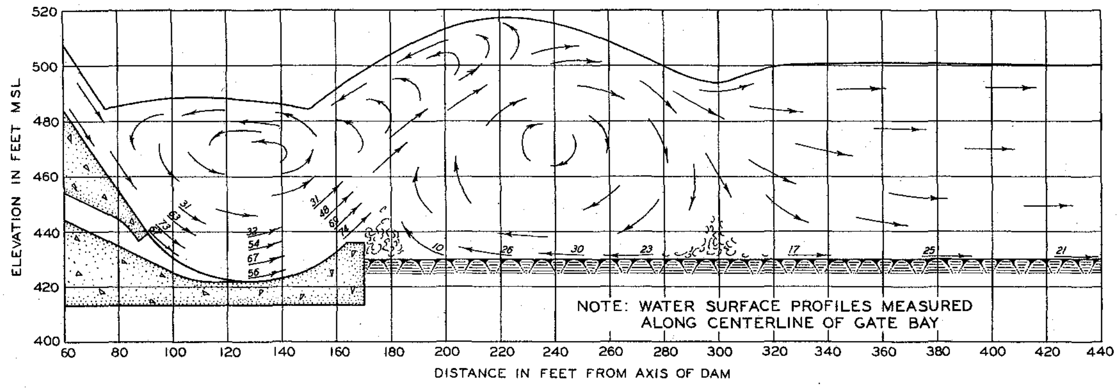
TYPE 3 APRON



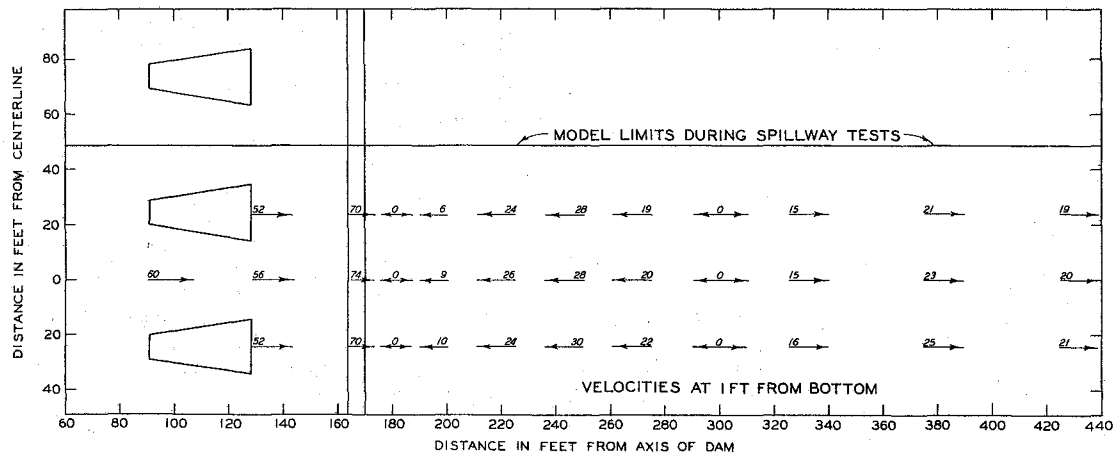
SECTION THROUGH
10 FT X 10 FT BAFFLE
PIER AND END SILL

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

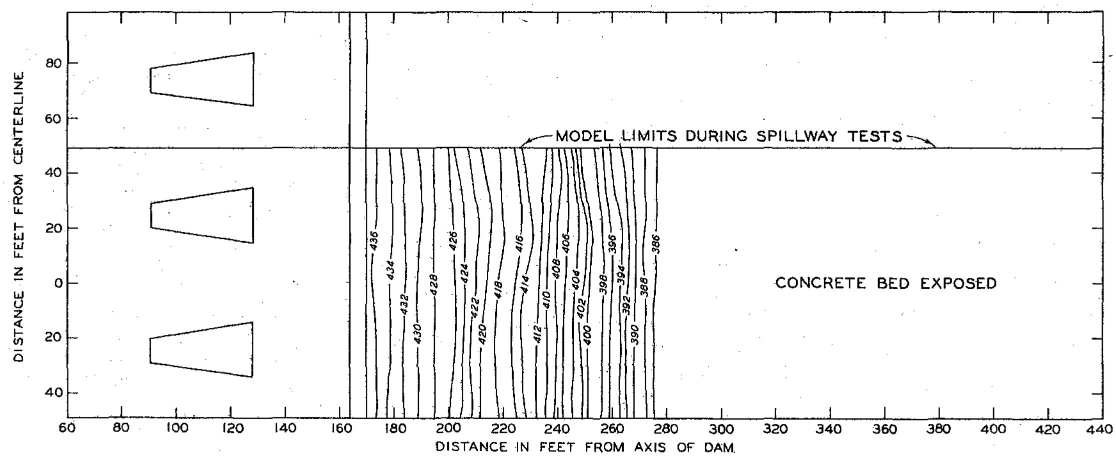
STILLING BASIN DESIGNS



WATER-SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

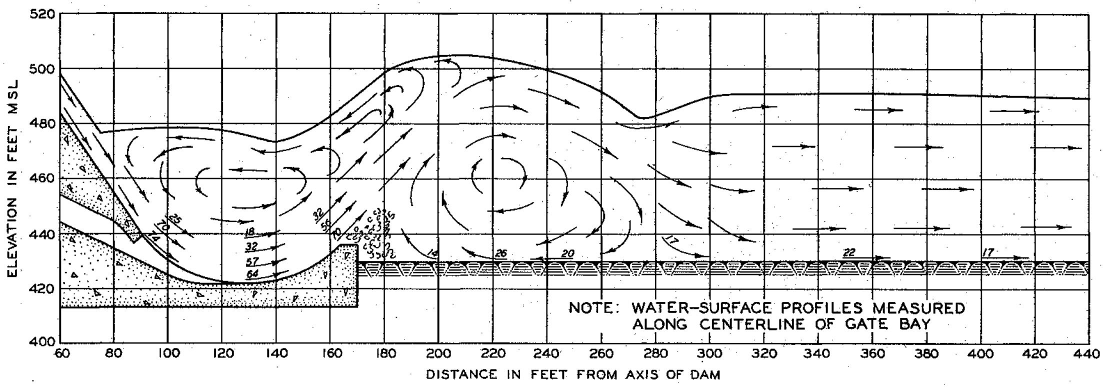
TEST CONDITIONS

DISCHARGE	660,000 CFS
POOL ELEVATION	572.12
TAILWATER ELEVATION	497.6
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

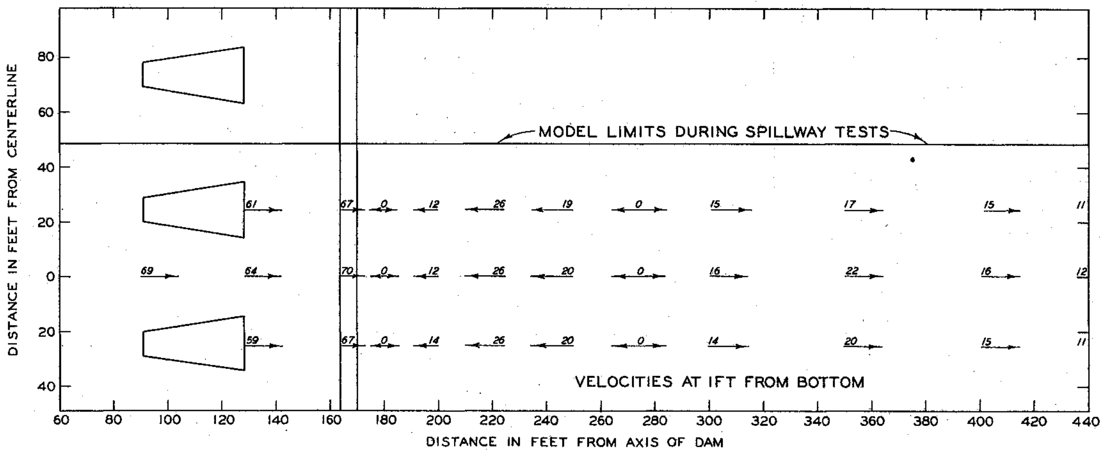
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

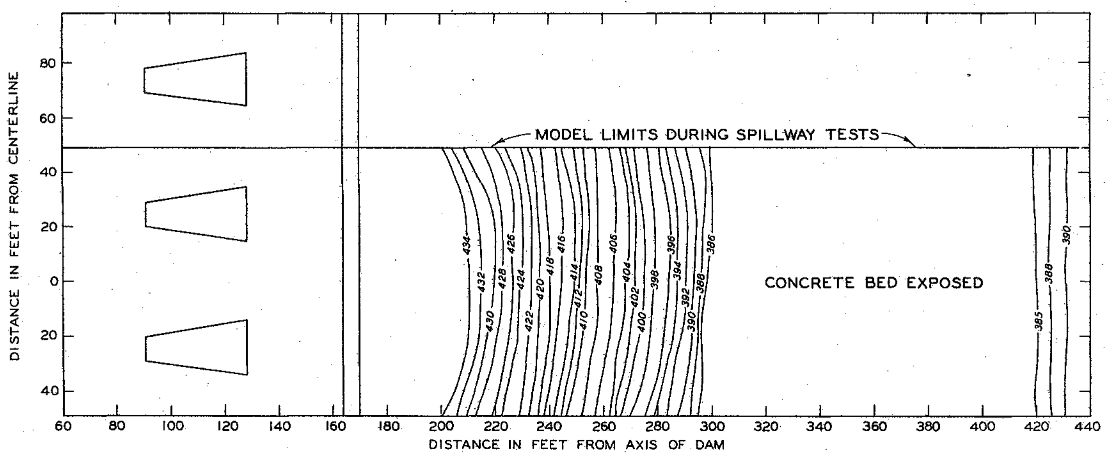
TYPE I BUCKET-ORIGINAL DESIGN
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

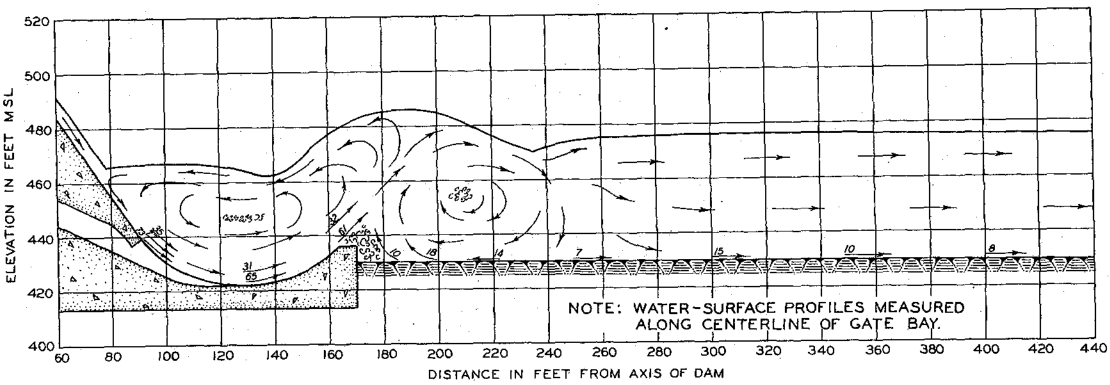
TEST CONDITIONS

DISCHARGE	450,000 CFS
POOL ELEVATION	564.19
TAILWATER ELEVATION	488.20
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

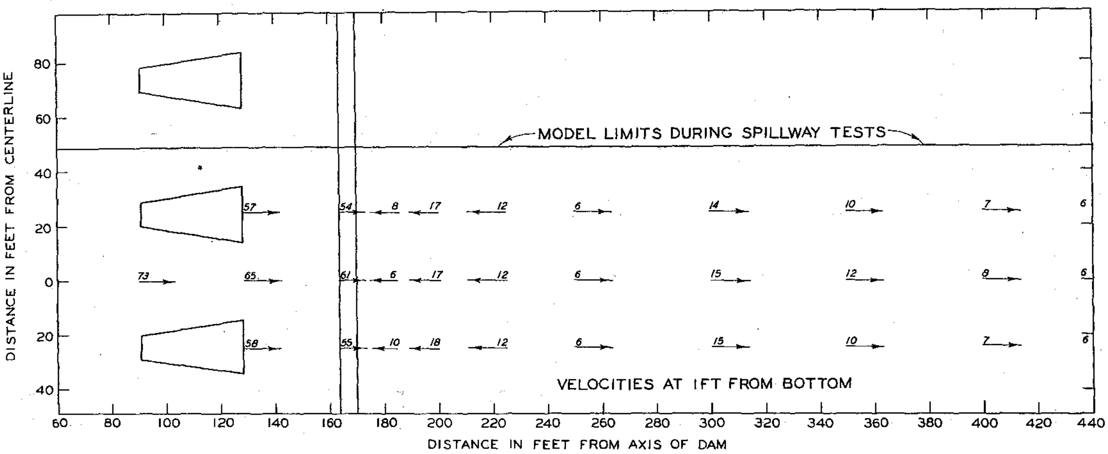
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

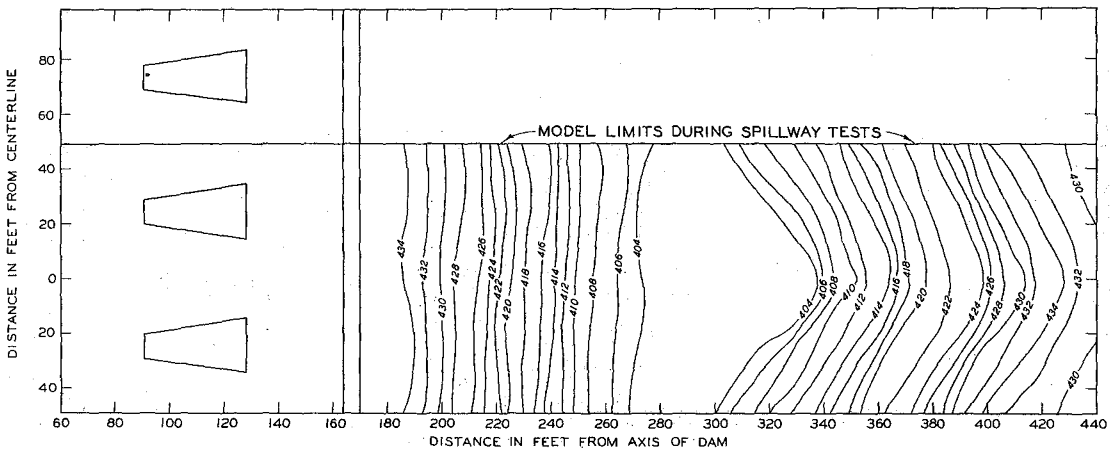
TYPE I BUCKET-ORIGINAL DESIGN
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

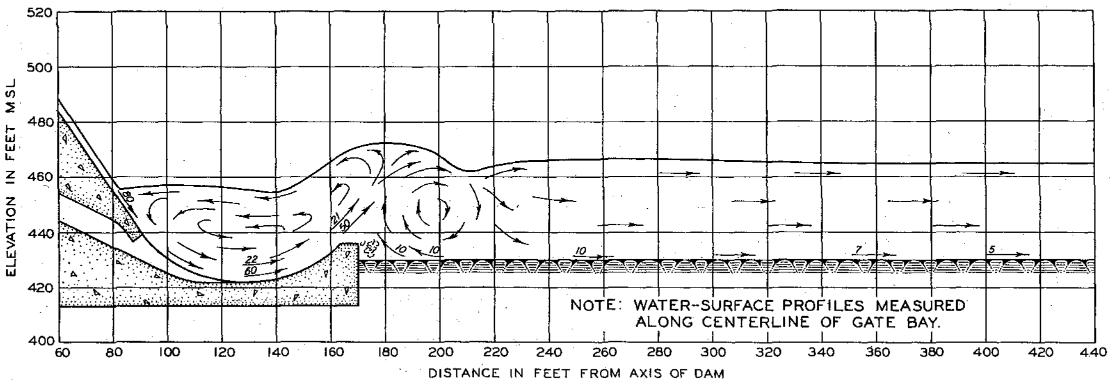
TEST CONDITIONS

DISCHARGE	250,000 CFS
POOL ELEVATION	555.03
TAILWATER ELEVATION	475.35
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

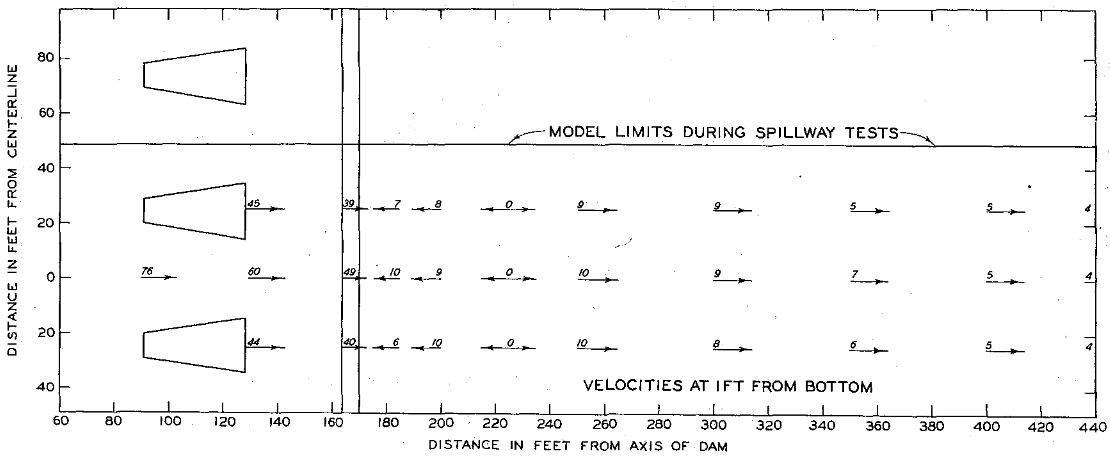
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

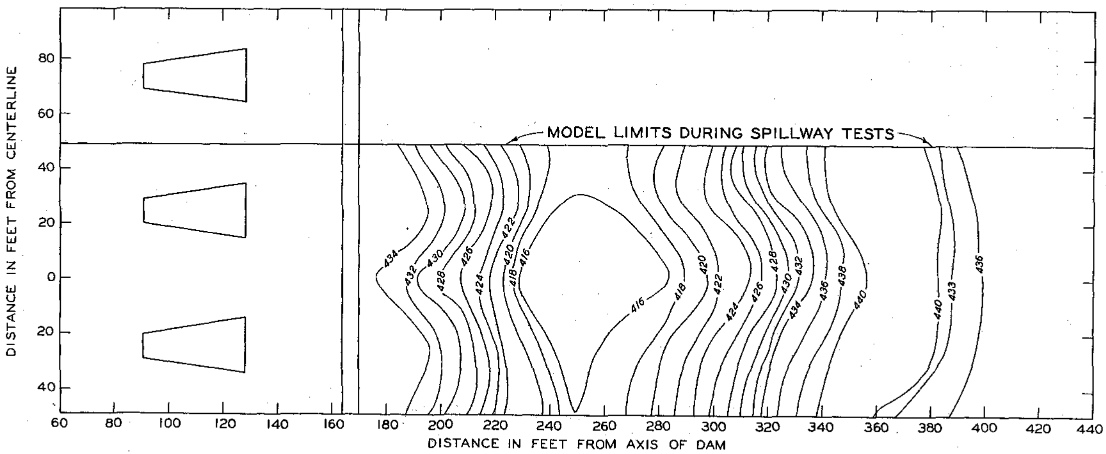
TYPE I BUCKET - ORIGINAL DESIGN
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

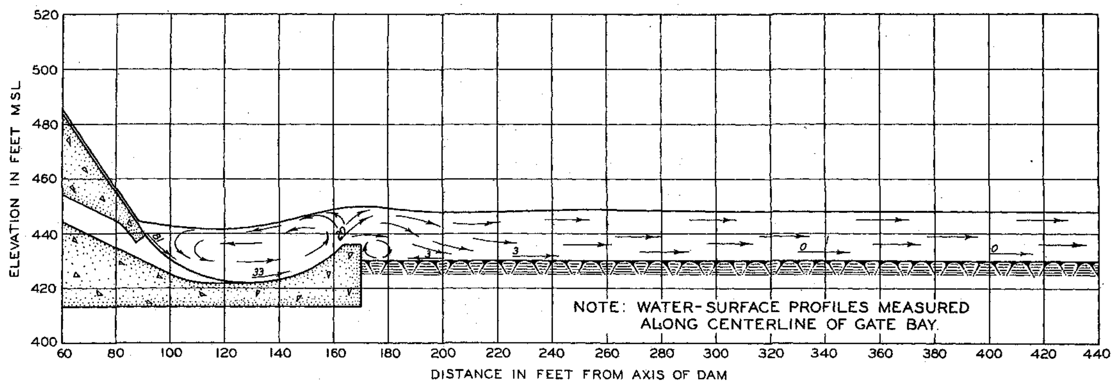
TEST CONDITIONS

DISCHARGE	150,000 CFS
POOL ELEVATION	548.93
TAILWATER ELEVATION	464.85
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

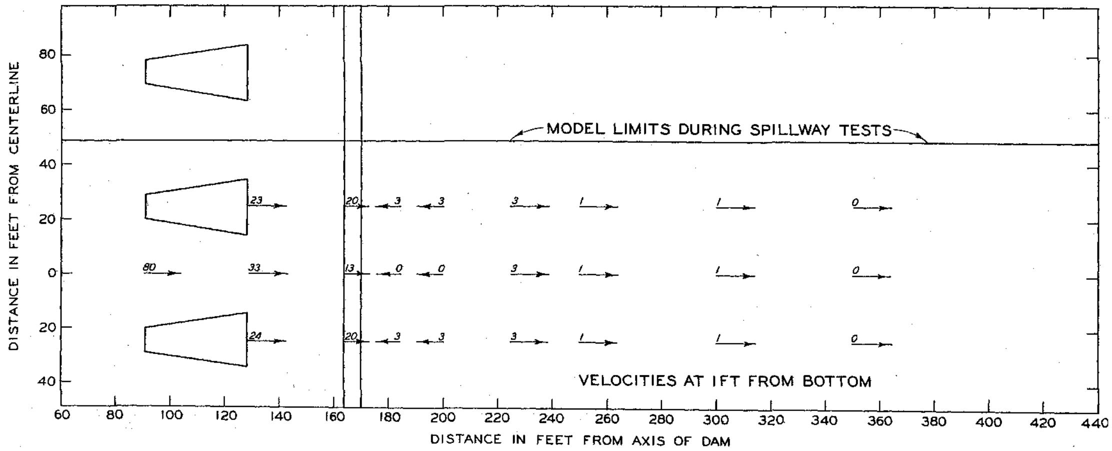
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

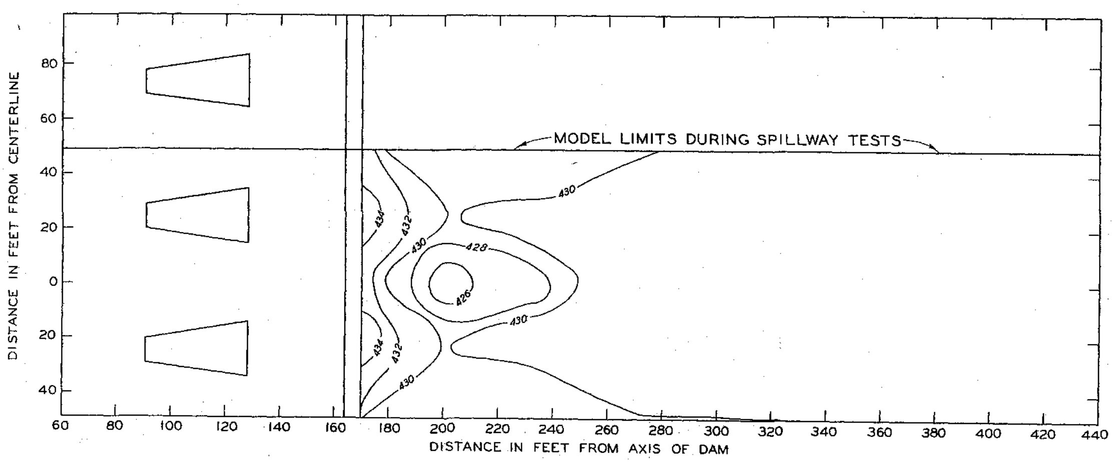
TYPE I BUCKET - ORIGINAL DESIGN
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

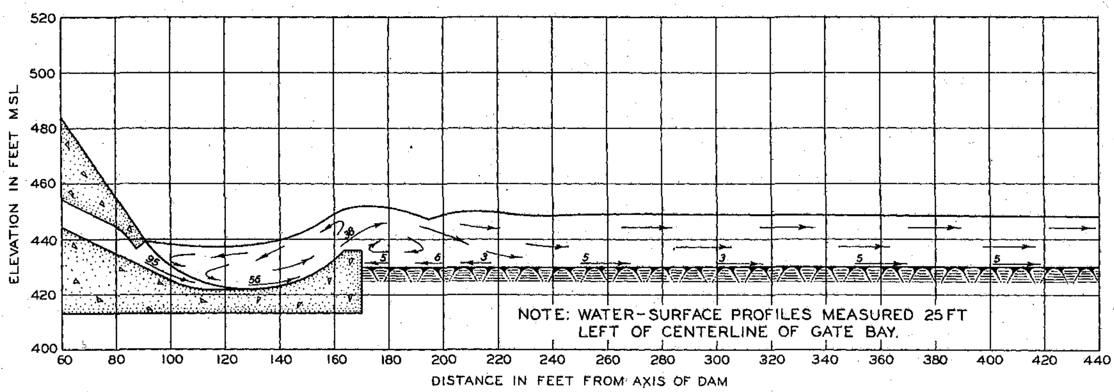
TEST CONDITIONS

DISCHARGE	50,000 CFS
POOL ELEVATION	540.86
TAILWATER ELEVATION	448.30
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

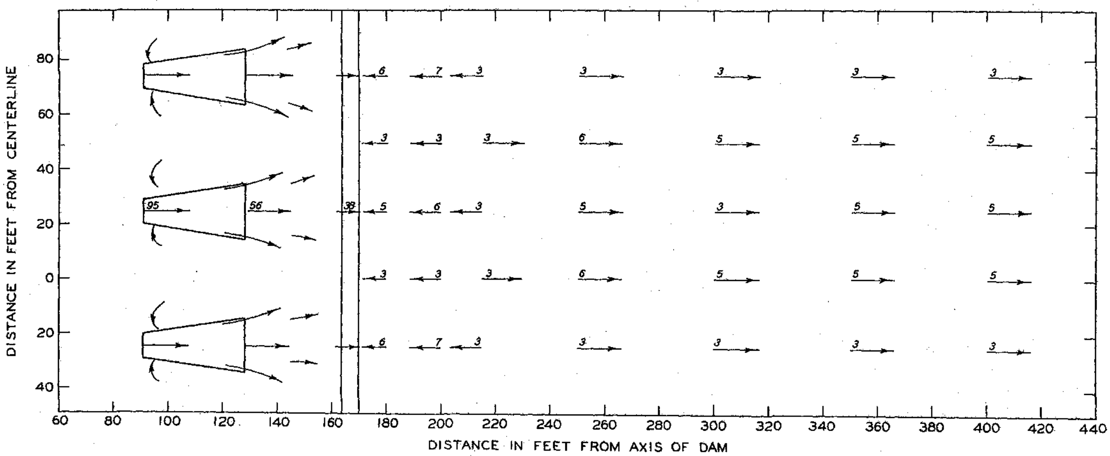
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

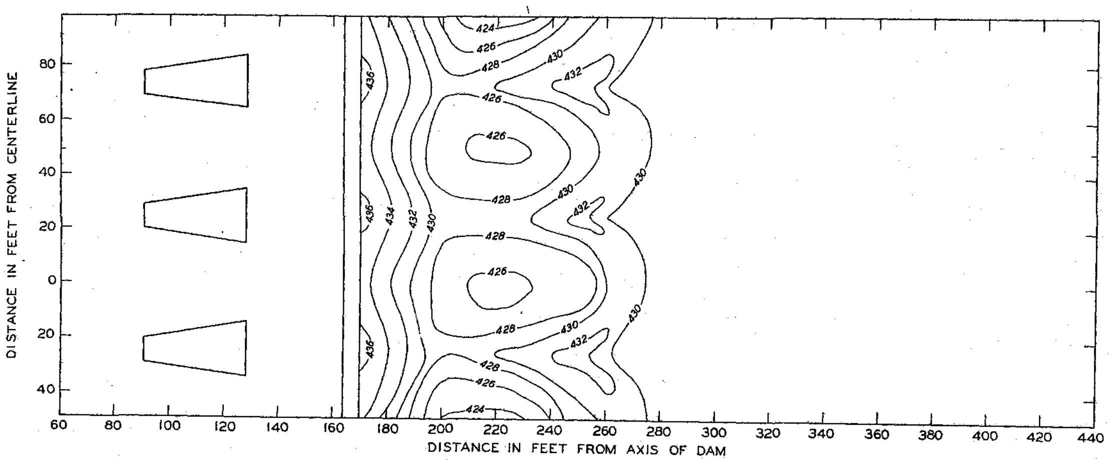
TYPE I BUCKET - ORIGINAL DESIGN
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

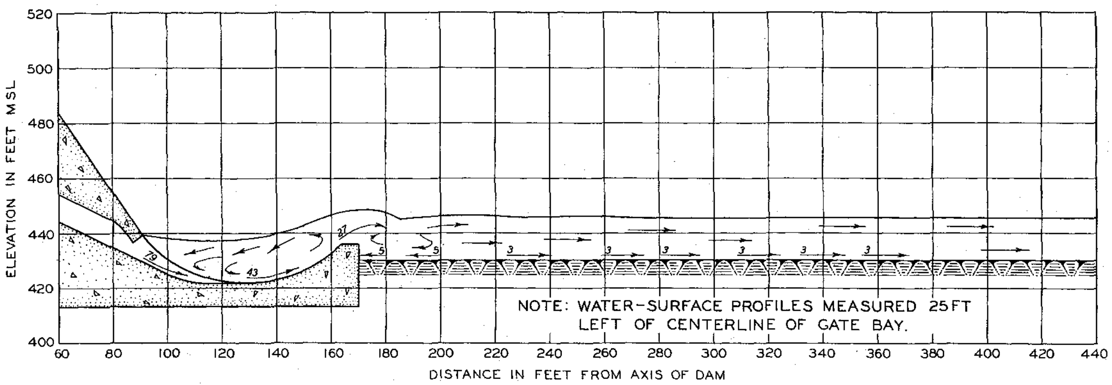
TEST CONDITIONS

DISCHARGE	50,000 CFS
16 CONDUITS OPERATING	
POOL ELEVATION	587.30
TAILWATER ELEVATION	448.30
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

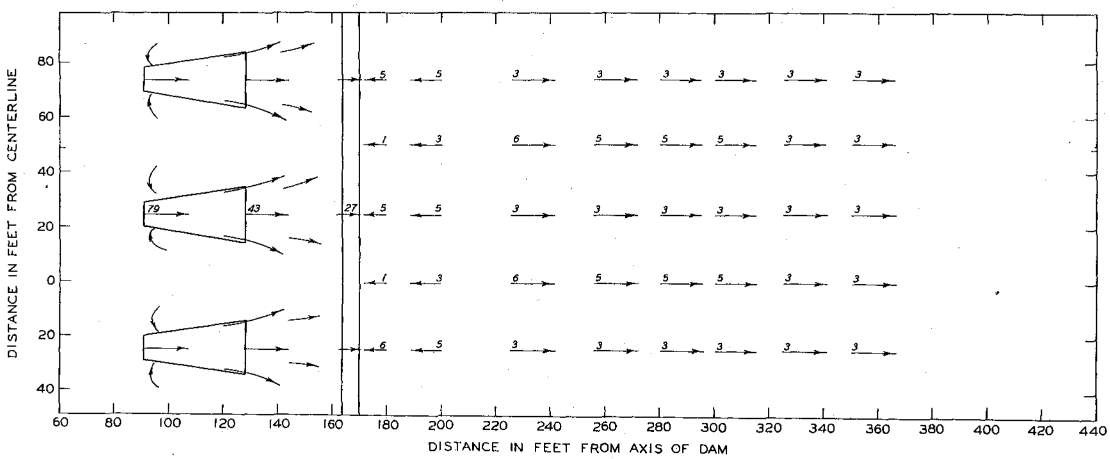
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE I BUCKET-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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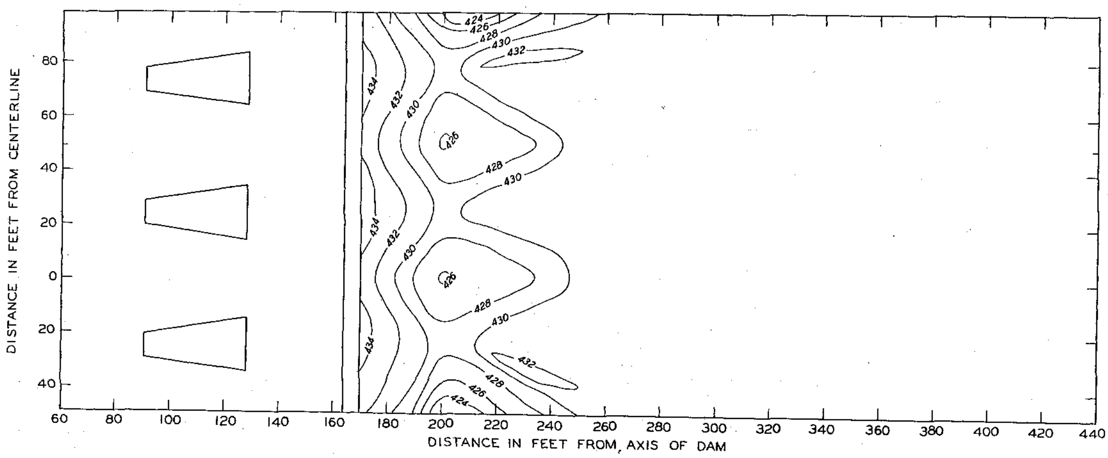


SCOUR PATTERN

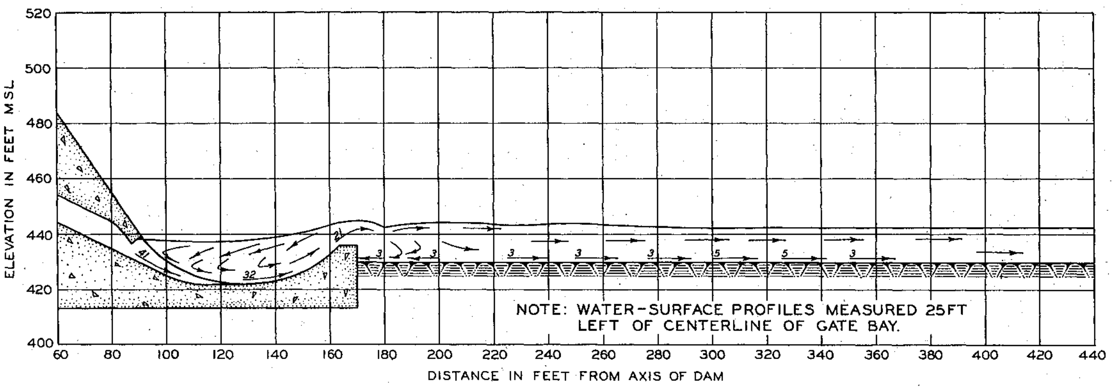
TEST CONDITIONS

DISCHARGE	40,000
16 CONDUITS OPERATING	
POOL ELEVATION	533.75
TAILWATER ELEVATION	445.60
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

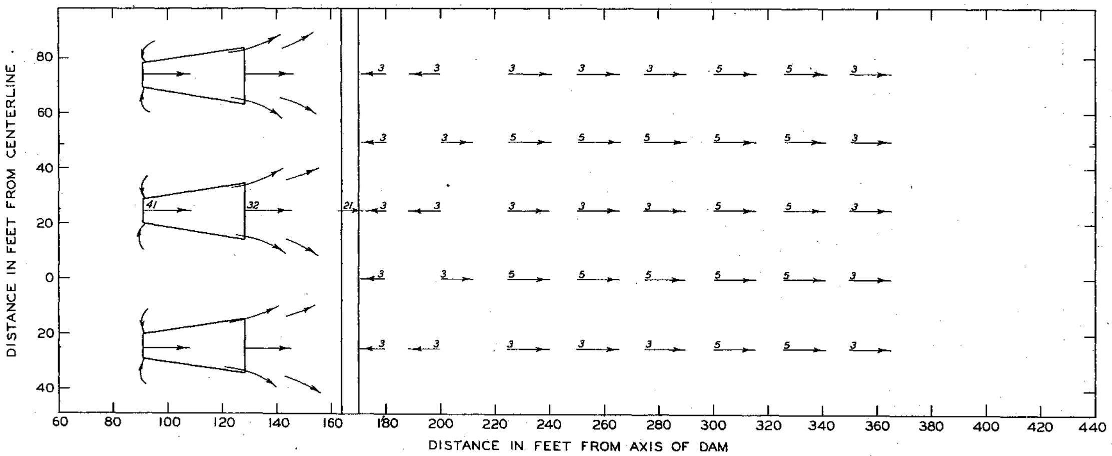
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE I BUCKET-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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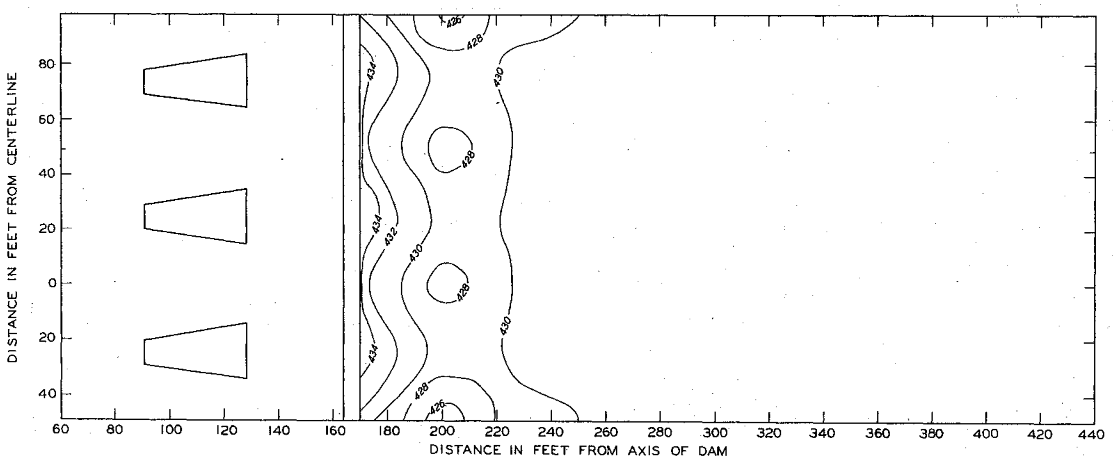


SCOUR PATTERN

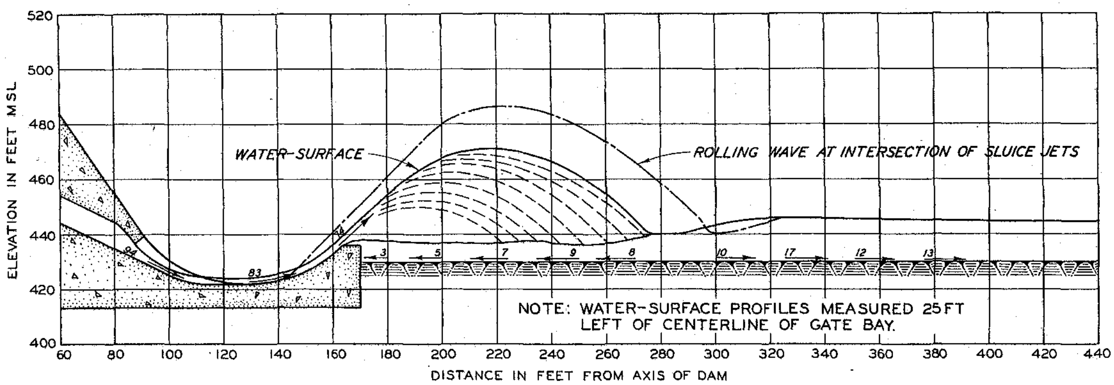
TEST CONDITIONS

DISCHARGE	30,000 CFS
16 CONDUITS OPERATING	
POOL ELEVATION	493.13
TAILWATER ELEVATION	442.3
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

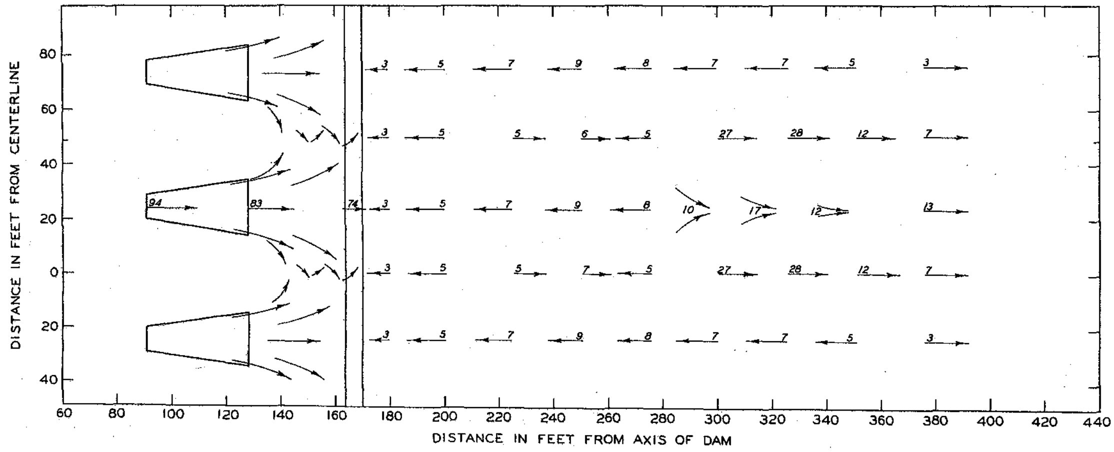
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE I BUCKET-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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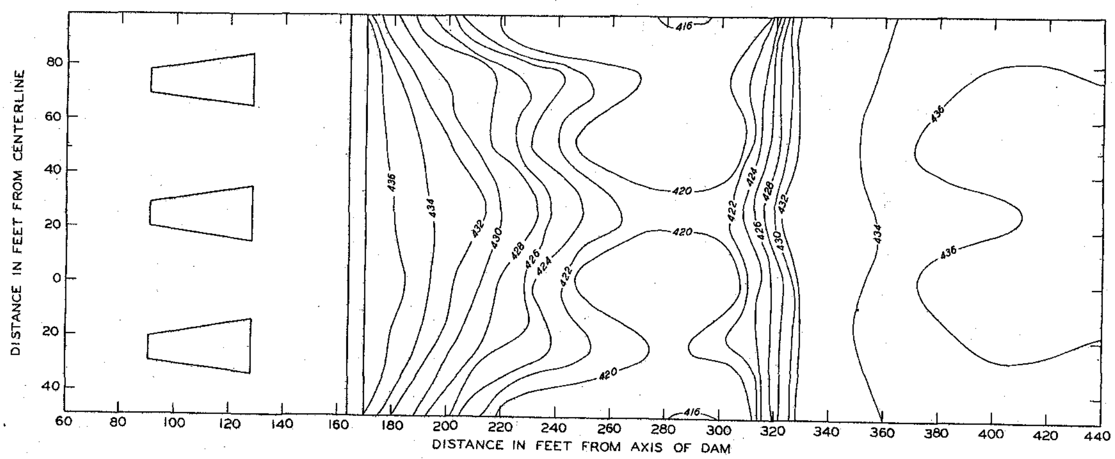


SCOUR PATTERN

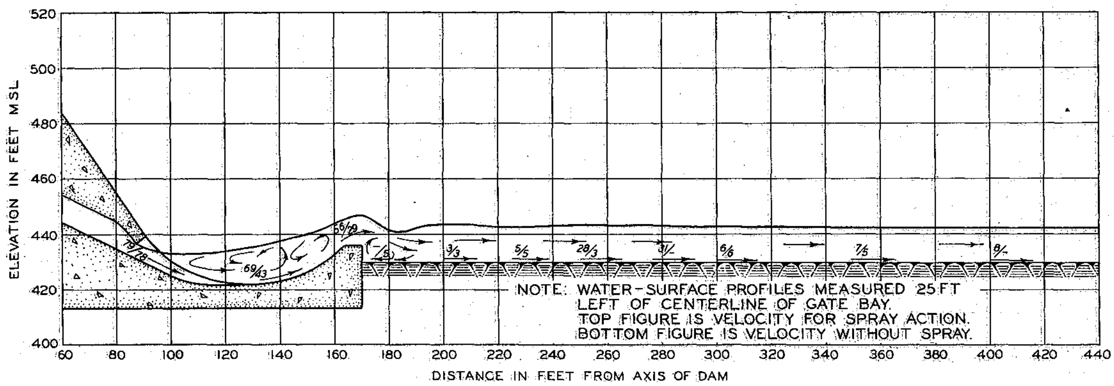
TEST CONDITIONS

DISCHARGE	36,000 CFS
12 CONDUITS OPERATING	
POOL ELEVATION	570.5
TAILWATER ELEVATION	444.4
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

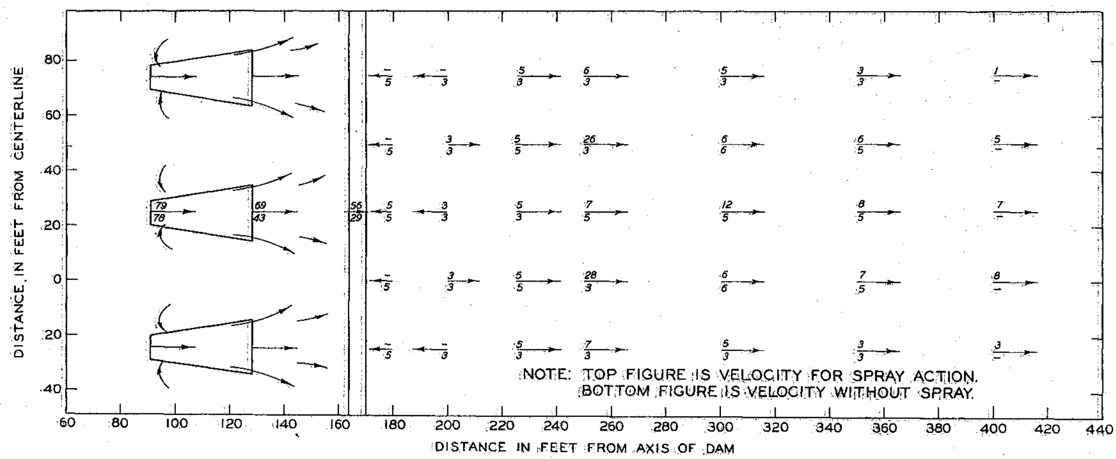
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE I BUCKET-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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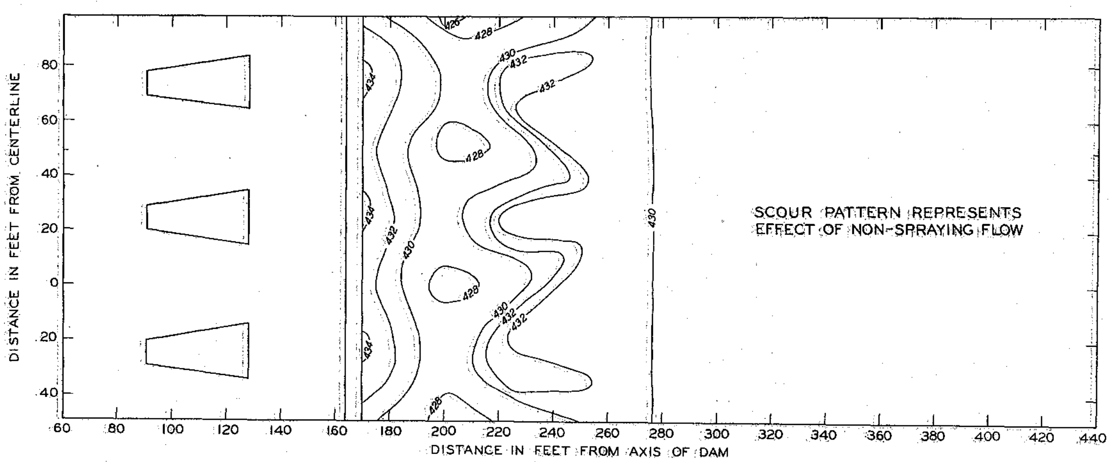


SCOUR PATTERN

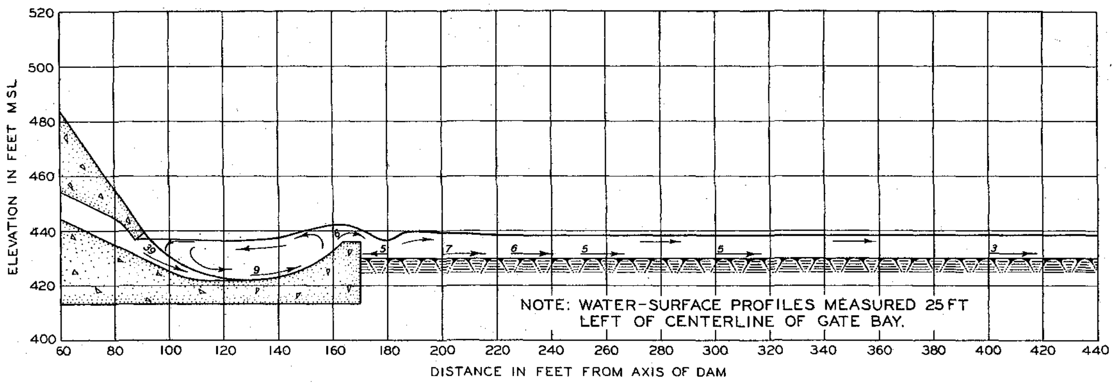
TEST CONDITIONS

DISCHARGE	30,000 CFS
12 CONDUITS OPERATING	
POOL ELEVATION	529.25
TAILWATER ELEVATION	442.28
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

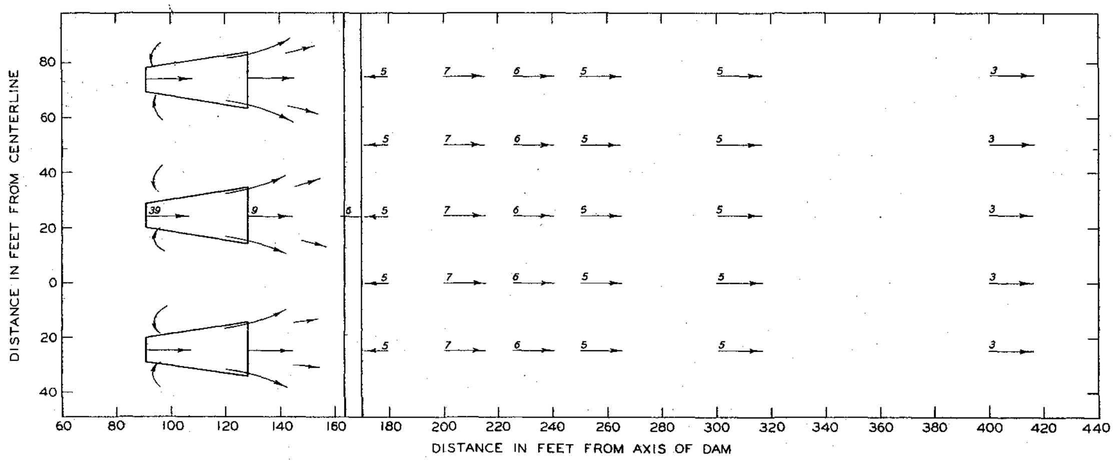
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE I BUCKET-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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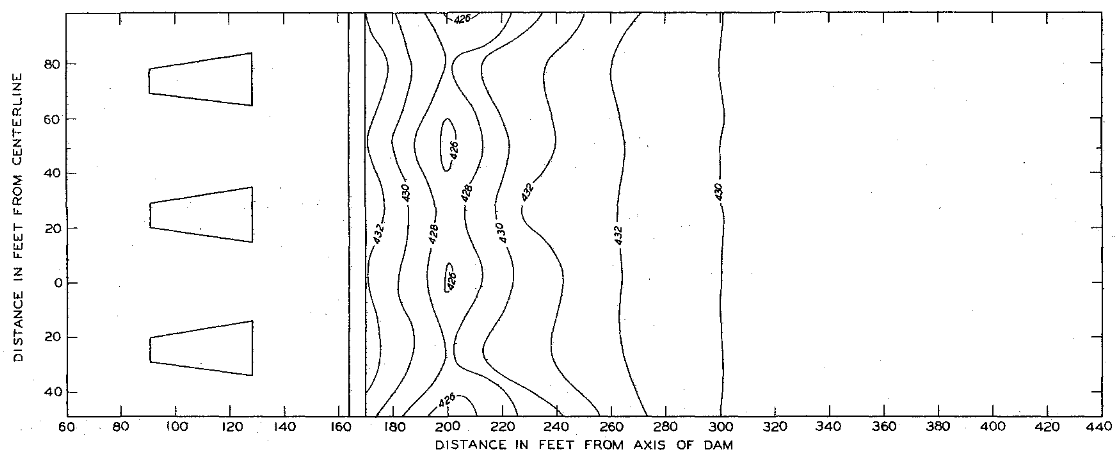


SCOUR PATTERN

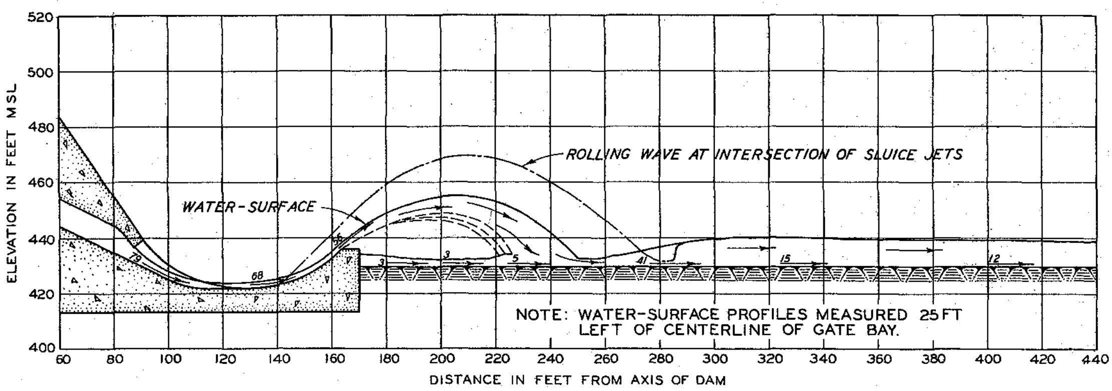
TEST CONDITIONS

DISCHARGE	20,000 CFS
12 CONDUITS OPERATING	
POOL ELEVATION	480.68
TAILWATER ELEVATION	438.35
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

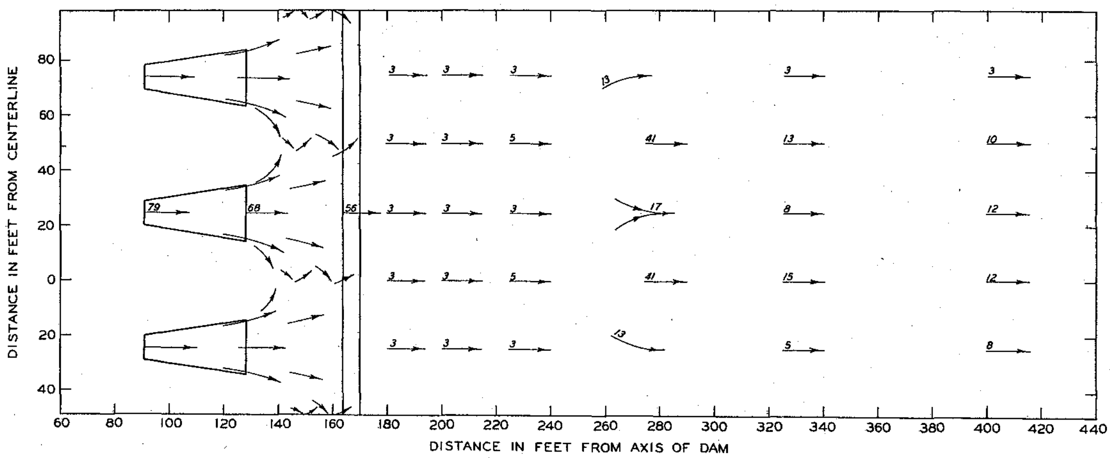
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE I BUCKET-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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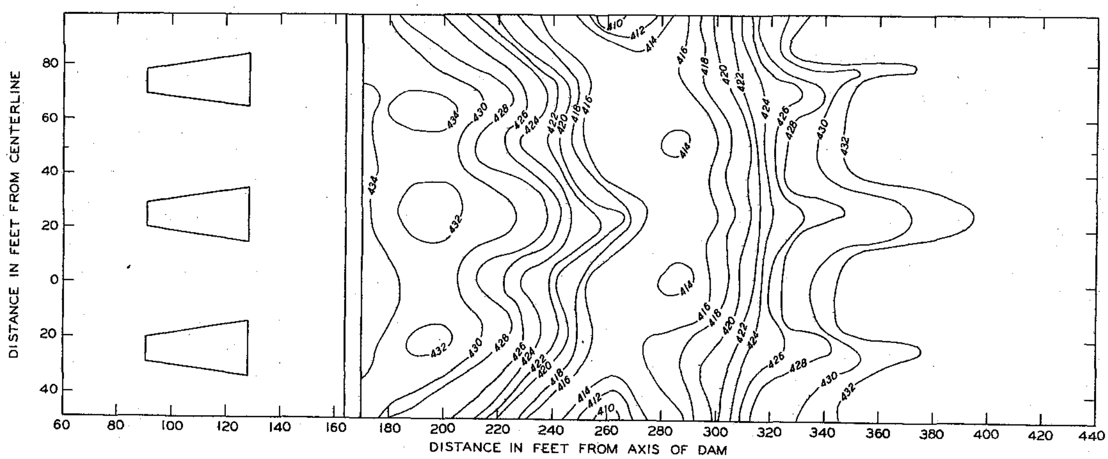


SCOUR PATTERN

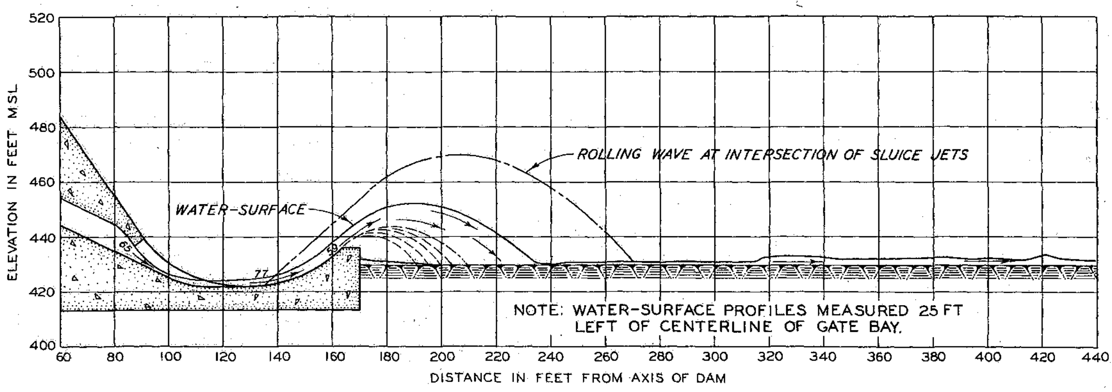
TEST CONDITIONS

DISCHARGE	20,000 CFS
8 CONDUITS OPERATING	
POOL ELEVATION	528.95
TAILWATER ELEVATION	438.35
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

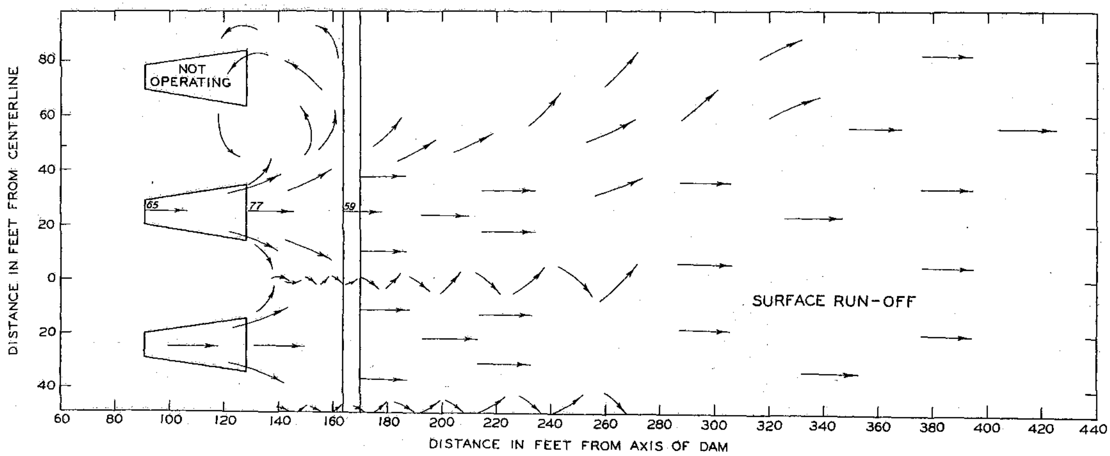
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE I BUCKET-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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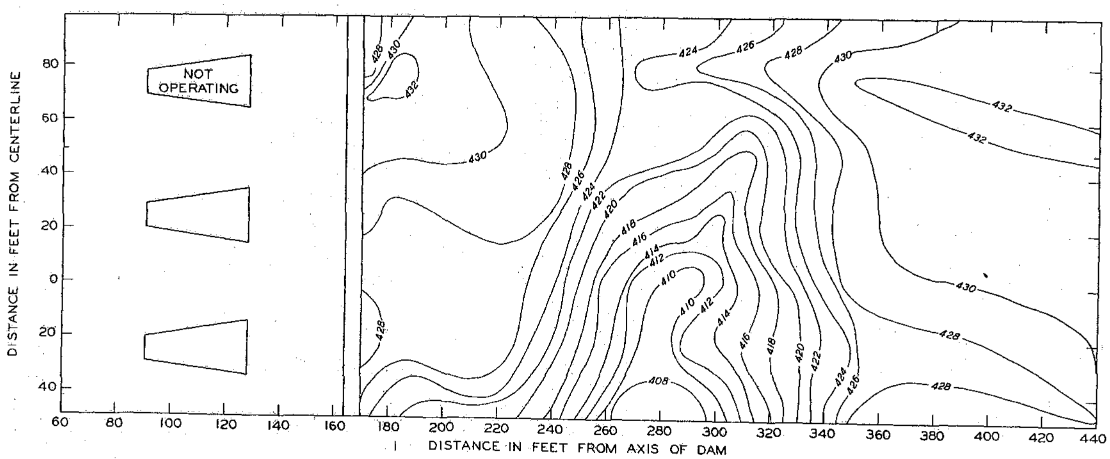


SCOUR PATTERN

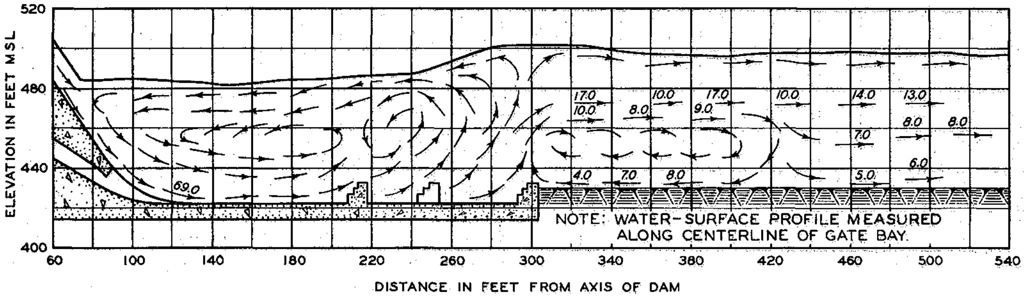
TEST CONDITIONS

DISCHARGE	5,000 CFS
2 CONDUITS OPERATING	
POOL ELEVATION	526.7
TAILWATER ELEVATION	431.4
BUCKET RADIUS	50 FT
LIP SLOPE	1 ON 1
BED MOLDED TO ELEVATION	430.0

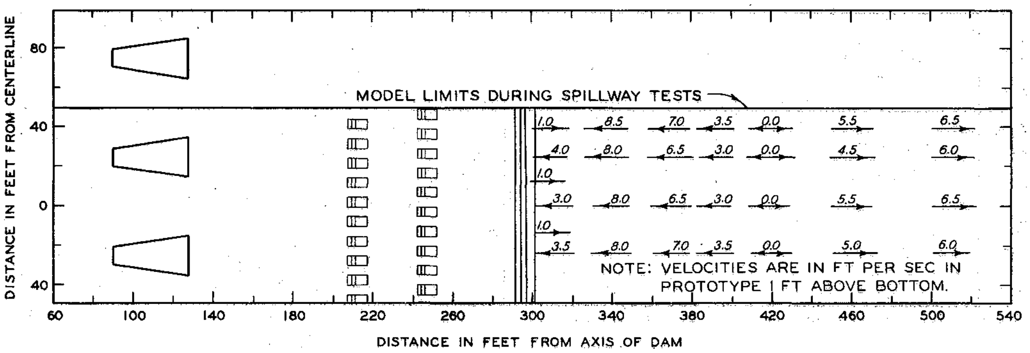
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE I BUCKET-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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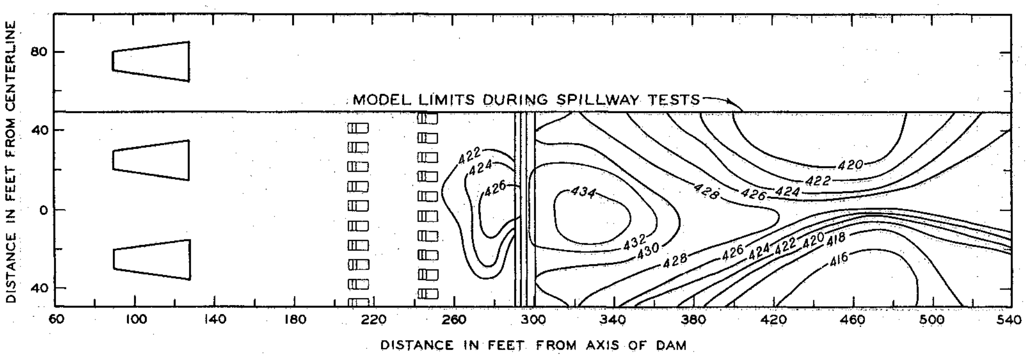


SCOUR PATTERN

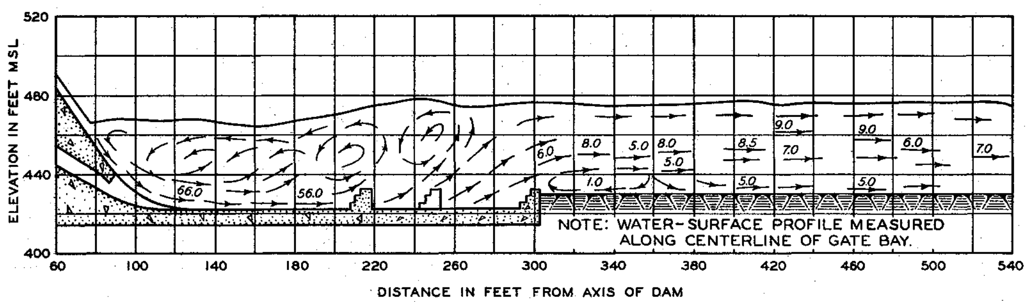
TEST CONDITIONS

DISCHARGE	660,000 CFS
POOL ELEVATION	572.12
TAILWATER ELEVATION	497.60
BED MOLDED TO ELEVATION	430.00

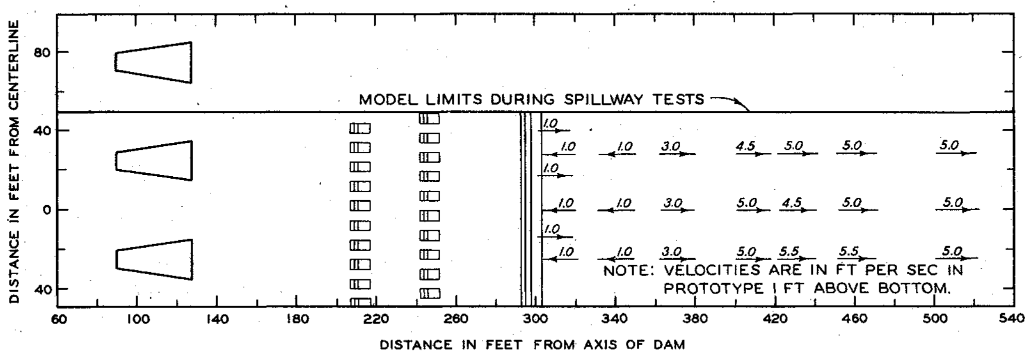
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 1 APRON - ORIGINAL DESIGN
SPILLWAY FLOW



WATER - SURFACE PROFILE AND CURRENTS



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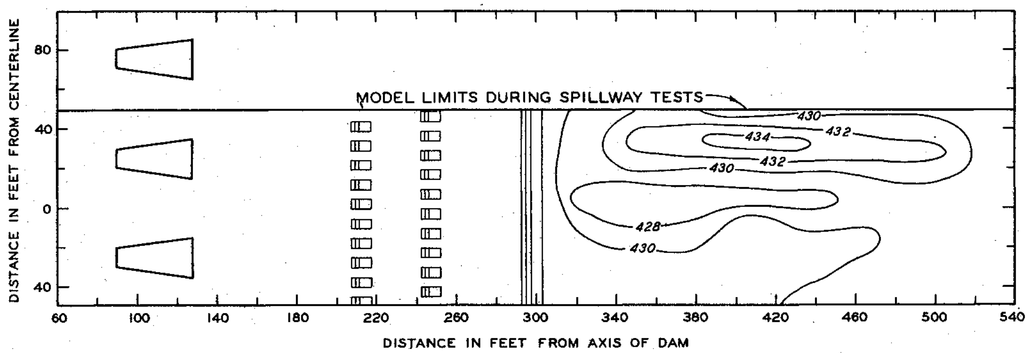


SCOUR PATTERN

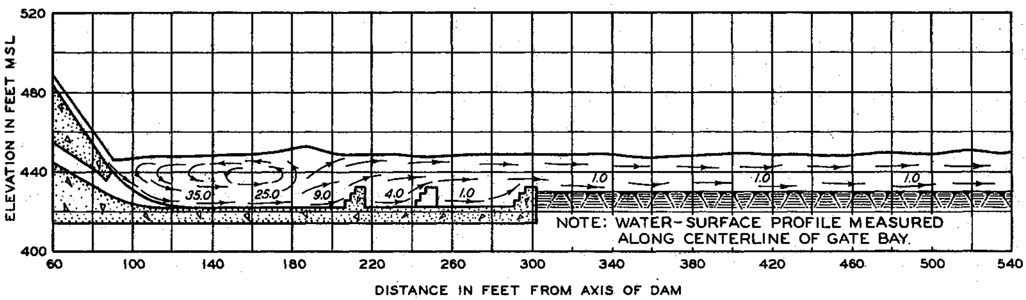
TEST CONDITIONS

DISCHARGE	250,000 CFS
POOL ELEVATION	555.03
TAILWATER ELEVATION	475.35
BED MOLDED TO ELEVATION	430.00

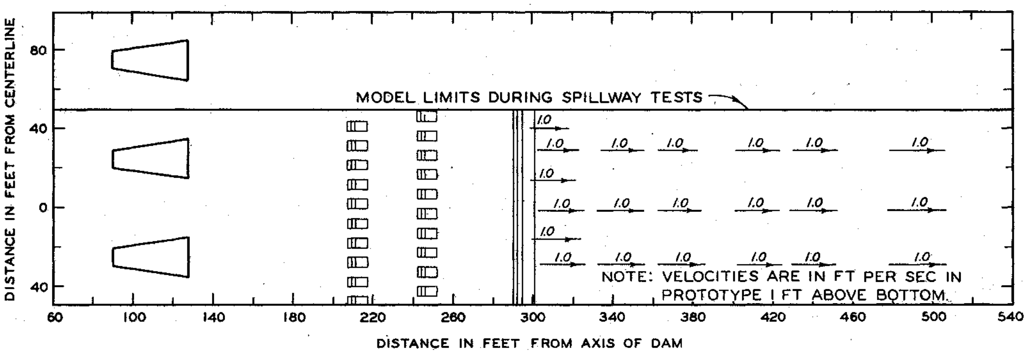
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 1 APRON - ORIGINAL DESIGN
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



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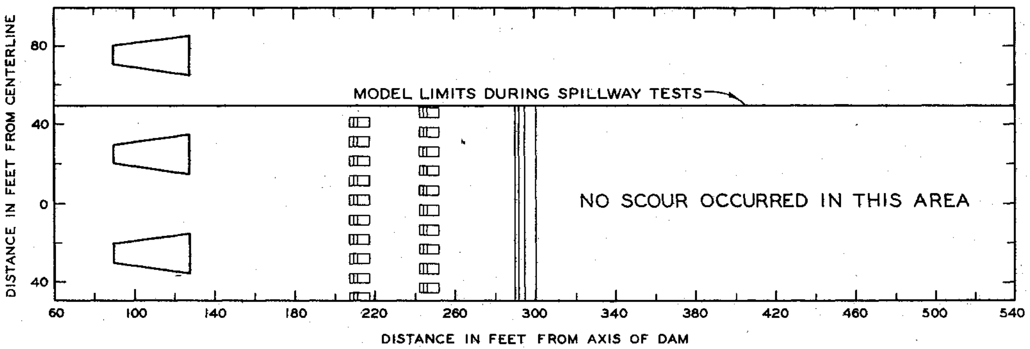


SCOUR PATTERN

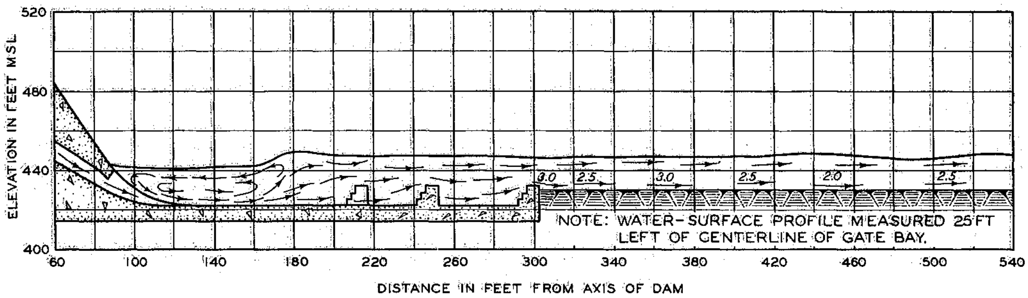
TEST CONDITIONS

DISCHARGE	50,000 CFS
POOL ELEVATION	540.86
TAILWATER ELEVATION	448.30
BED MOLDED TO ELEVATION	430.00

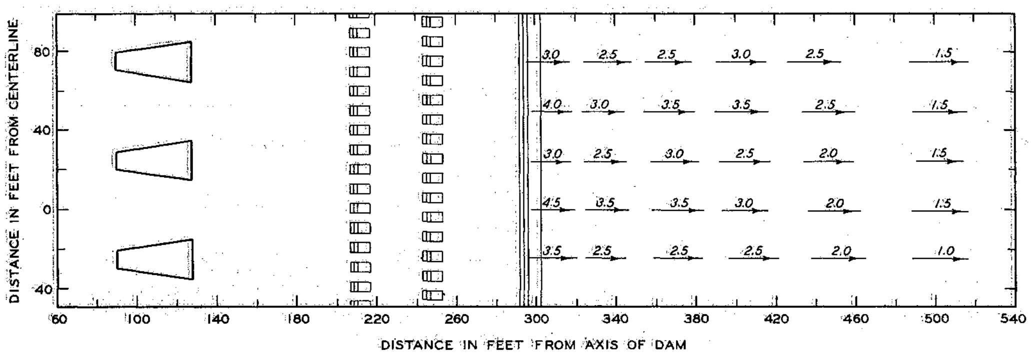
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

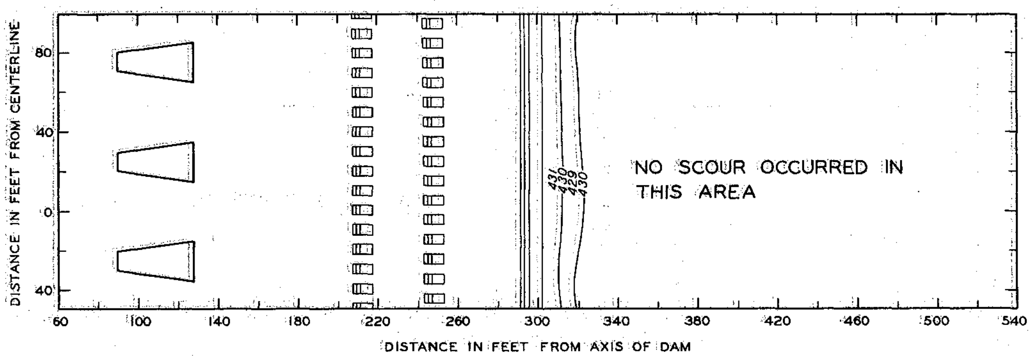
TYPE I APRON - ORIGINAL DESIGN
SPILLWAY FLOW



WATER - SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

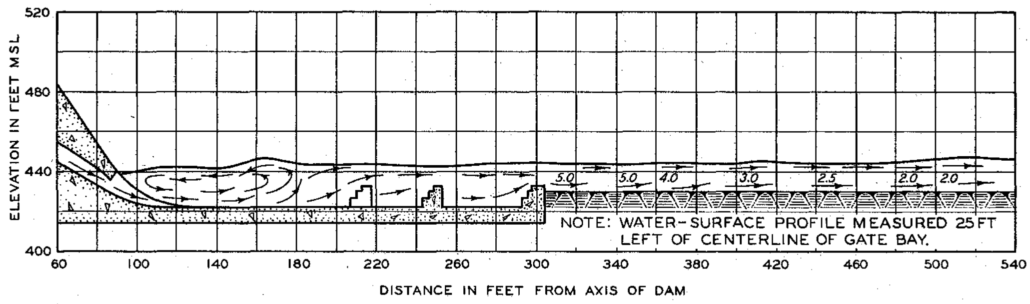
TEST CONDITIONS

DISCHARGE	46,400 CFS
16 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	448.0
BED MOLDED TO ELEVATION	430.0

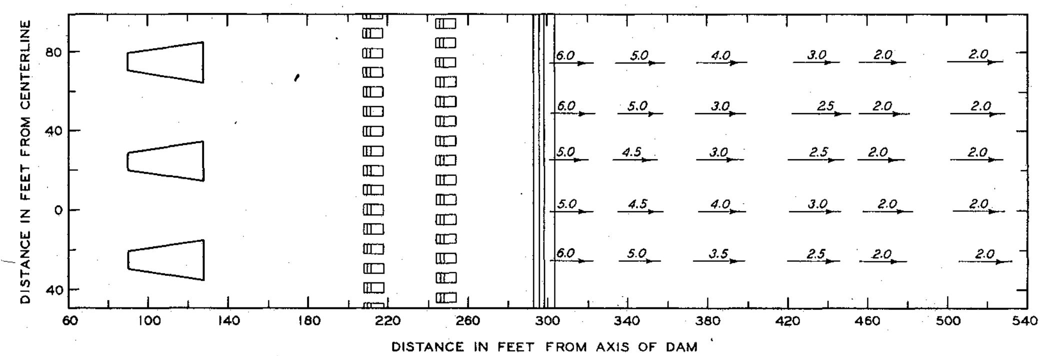
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE I APRON–ORIGINAL DESIGN
CONDUIT FLOW



WATER - SURFACE PROFILE AND CURRENTS



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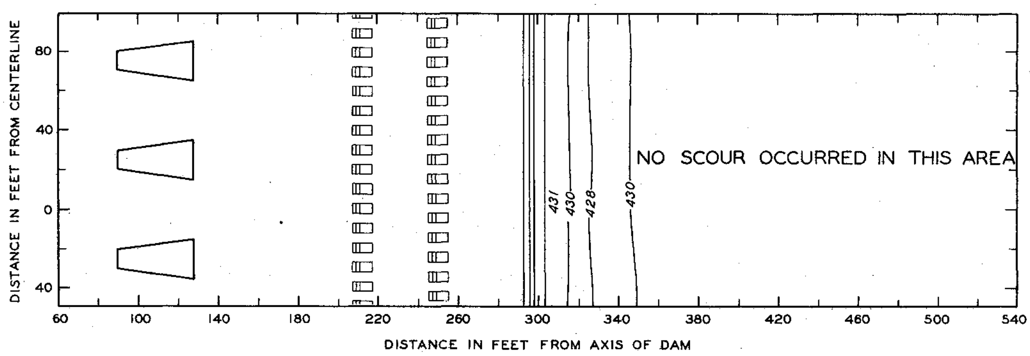


SCOUR PATTERN

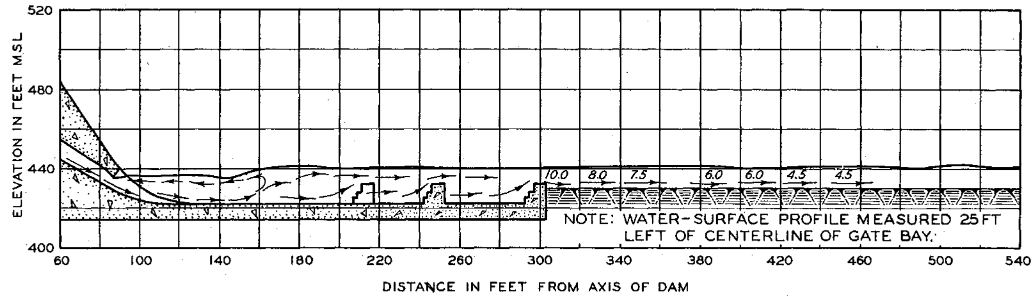
TEST CONDITIONS

DISCHARGE	36,000 CFS
12 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	444.4
BED MOLDED TO ELEVATION	430.0

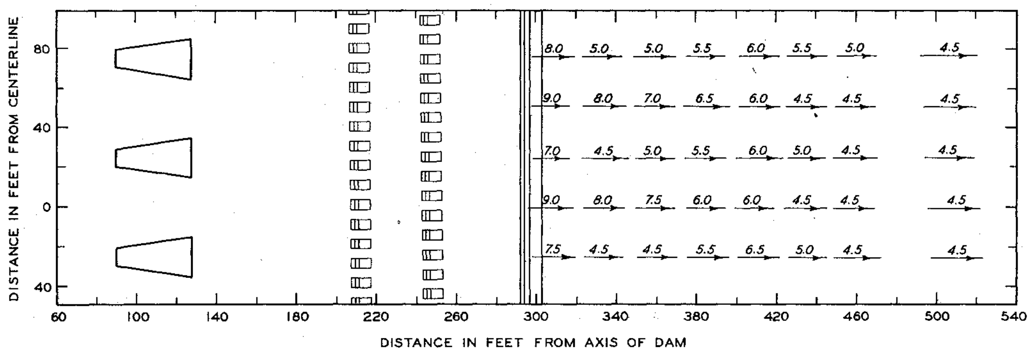
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

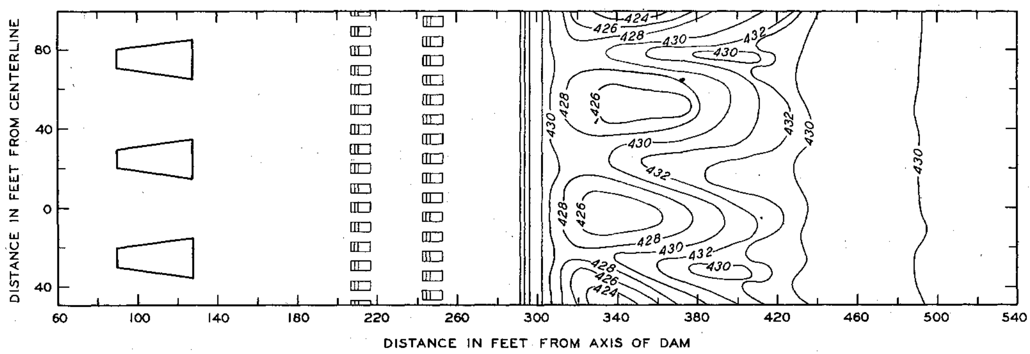
TYPE I APRON-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

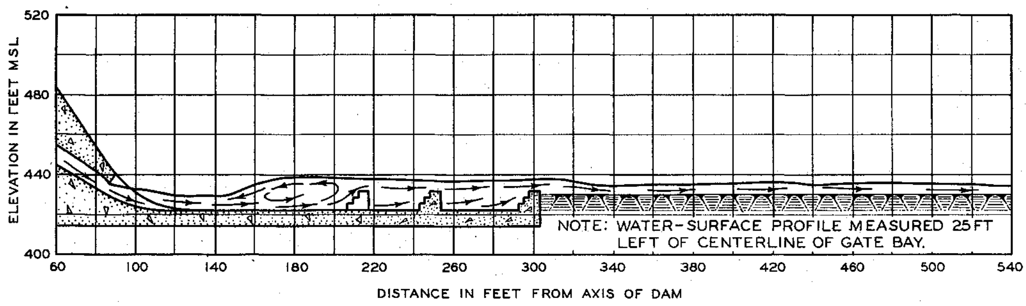
TEST CONDITIONS

DISCHARGE	24,000 CFS
8 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	440.4
BED MOLDED TO ELEVATION	430.0

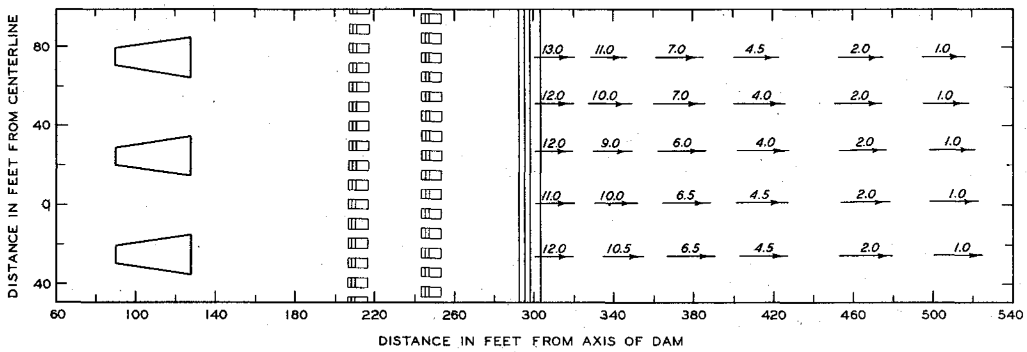
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

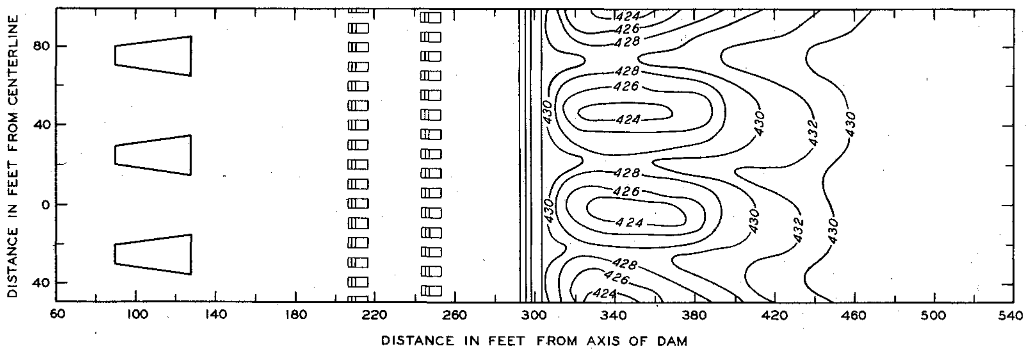
TYPE I APRON-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

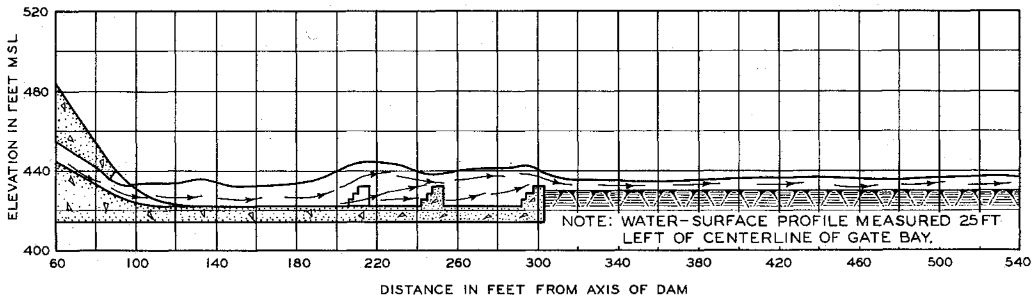
TEST CONDITIONS

DISCHARGE	9,000 CFS
3 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	437.0
BED MOLDED TO ELEVATION	430.0

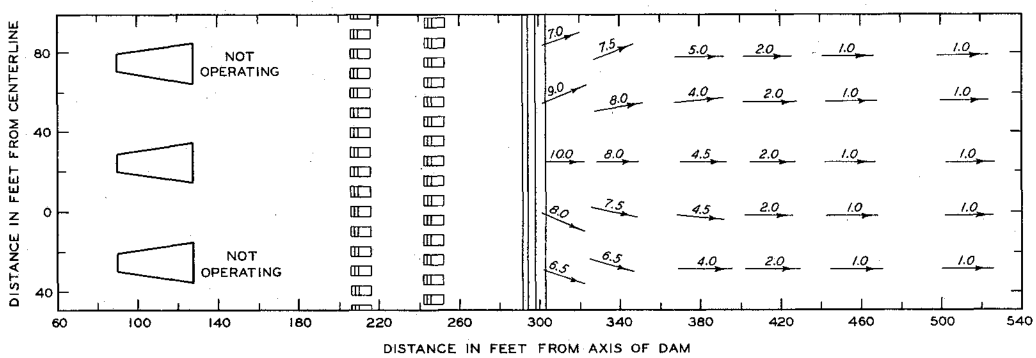
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

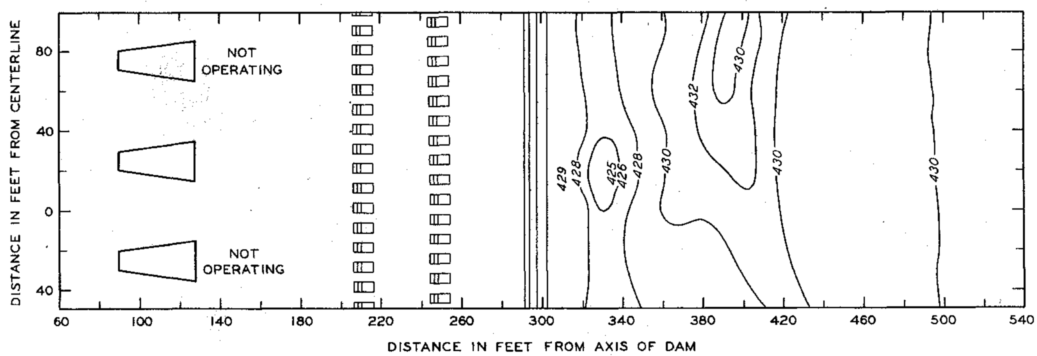
TYPE I APRON-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

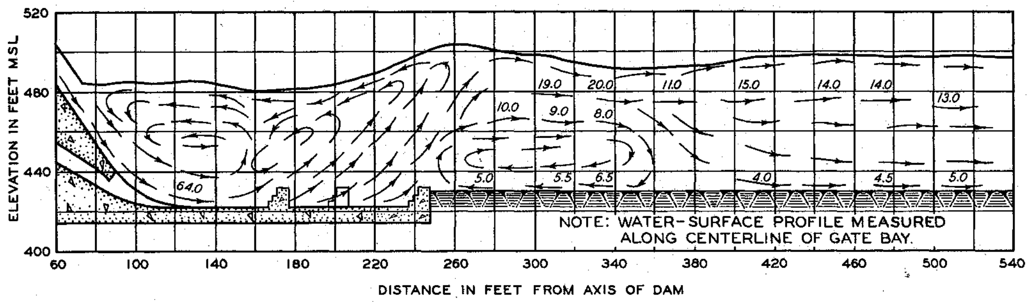
TEST CONDITIONS

DISCHARGE	3,000 CFS
1 CONDUIT OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	436.0
BED MOLDED TO ELEVATION	430.0

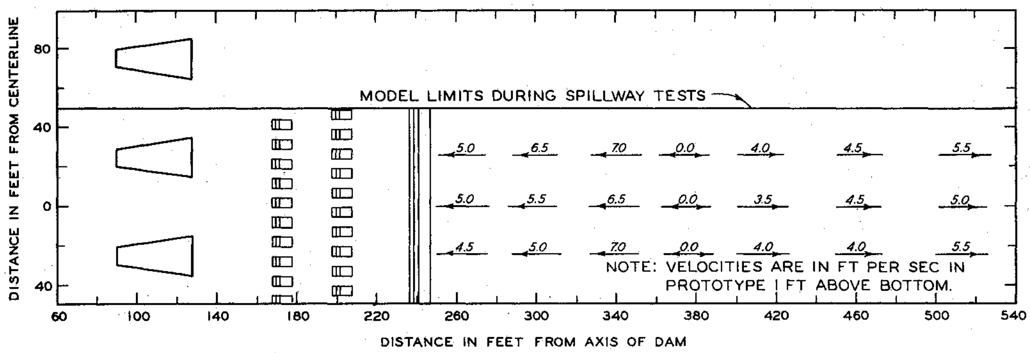
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

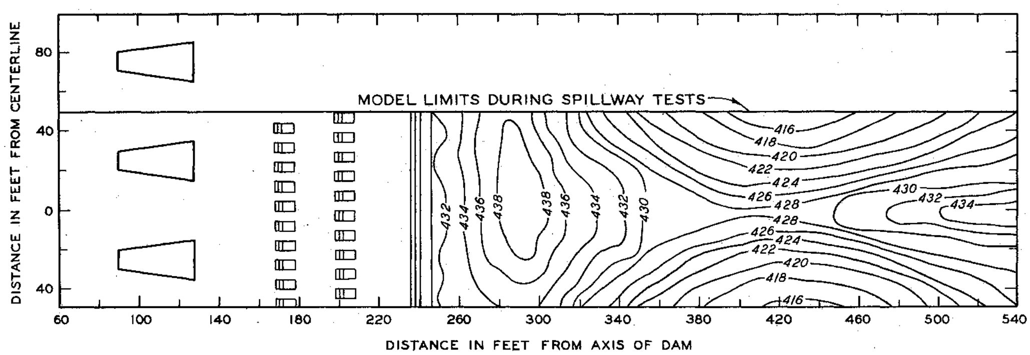
TYPE I APRON-ORIGINAL DESIGN
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

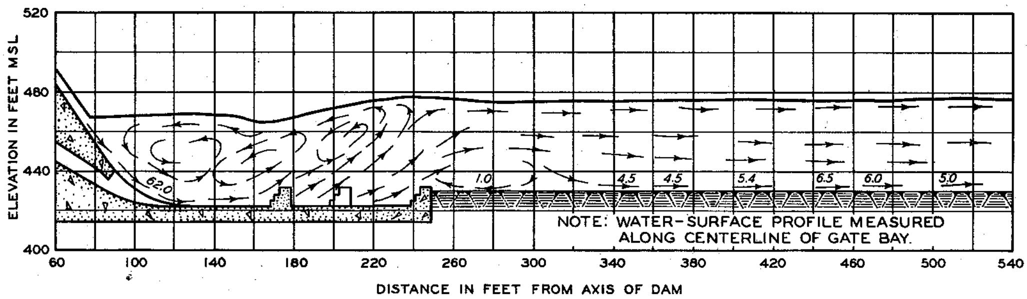
TEST CONDITIONS

DISCHARGE	660,000 CFS
POOL ELEVATION	572.12
TAILWATER ELEVATION	497.60
BED MOLDED TO ELEVATION	430.00

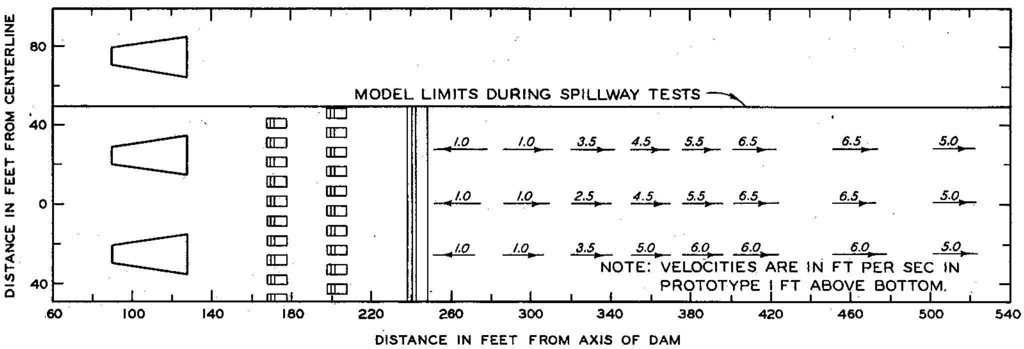
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

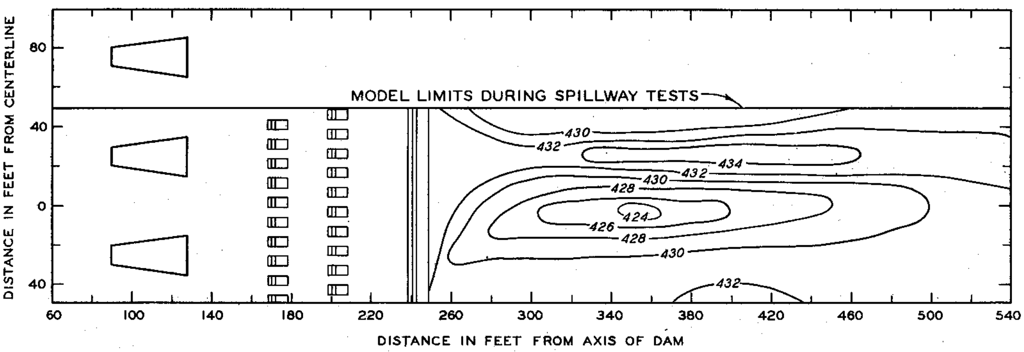
TYPE 2 APRON
SPILLWAY FLOW



WATER - SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

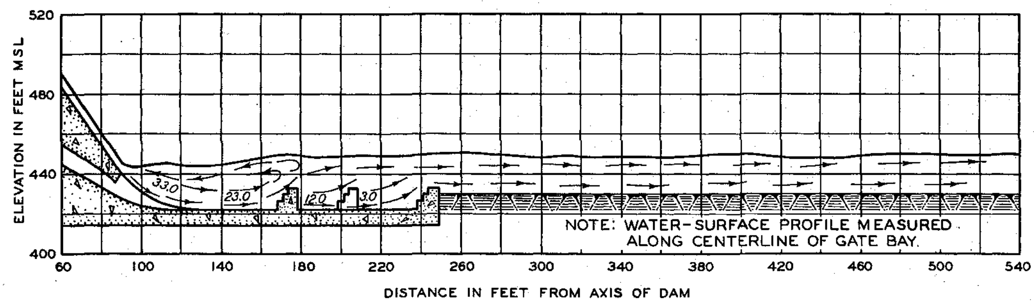
TEST CONDITIONS

DISCHARGE	250,000 CFS
POOL ELEVATION	555.03
TAILWATER ELEVATION	475.35
BED MOLDED TO ELEVATION	430.00

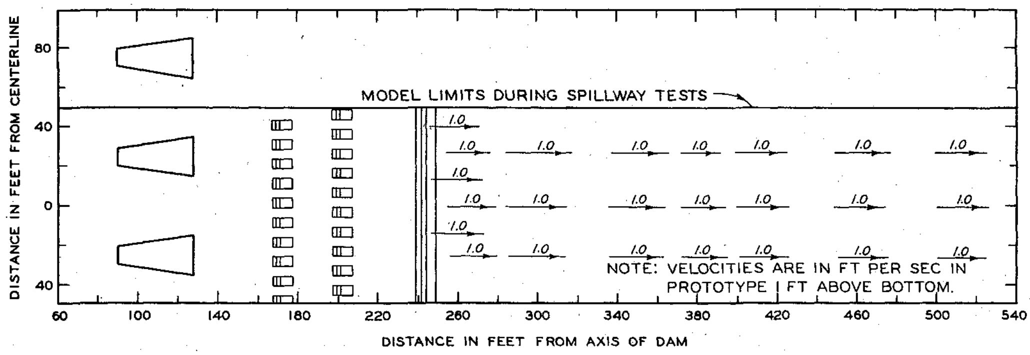
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 2 APRON
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



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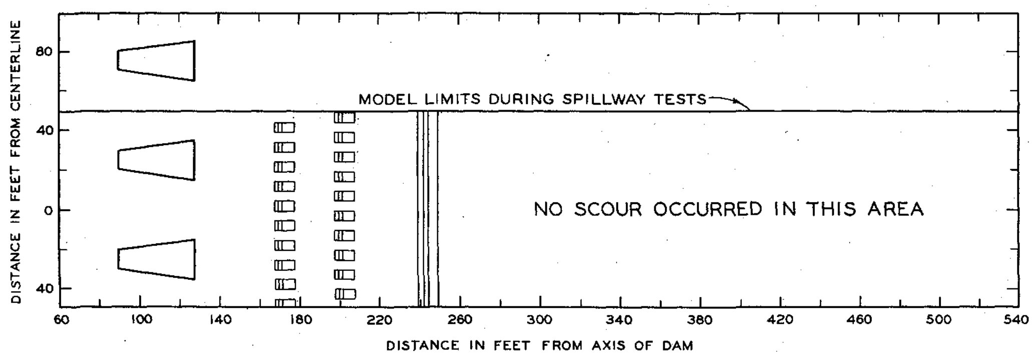


SCOUR PATTERN

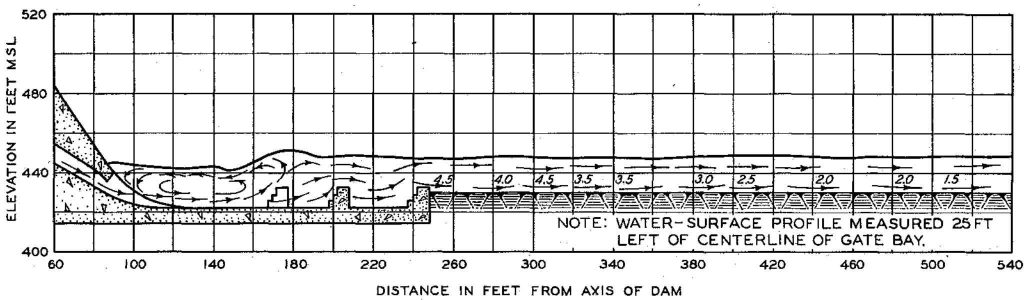
TEST CONDITIONS

DISCHARGE	50,000 CFS
POOL ELEVATION	540.86
TAILWATER ELEVATION	448.30
BED MOLDED TO ELEVATION	430.00

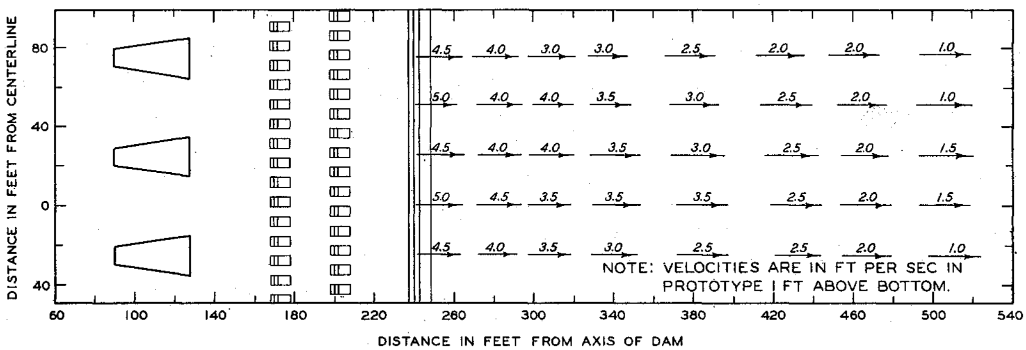
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 2 APRON
SPILLWAY FLOW



WATER - SURFACE PROFILE AND CURRENTS



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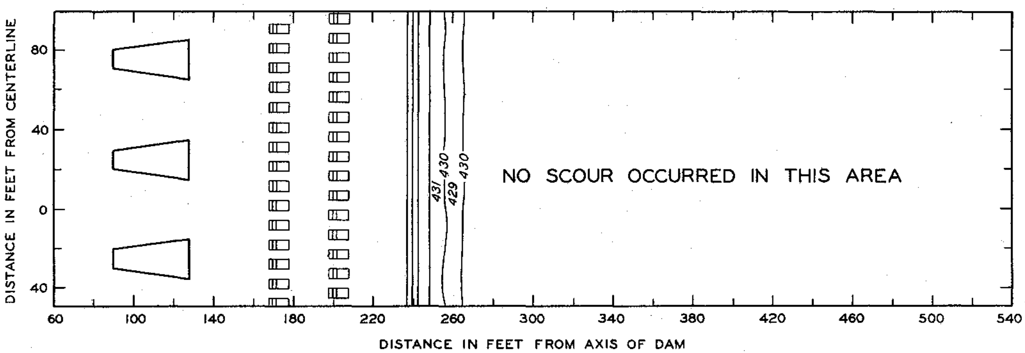


SCOUR PATTERN

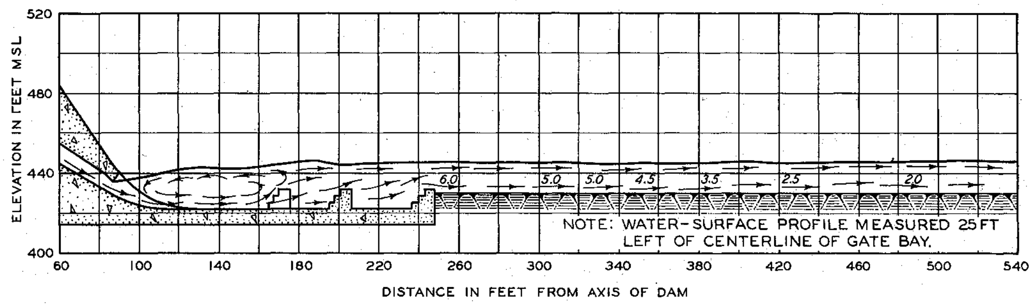
TEST CONDITIONS

DISCHARGE	46,400 CFS
16 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	448.0
BED MOLDED TO ELEVATION	430.0

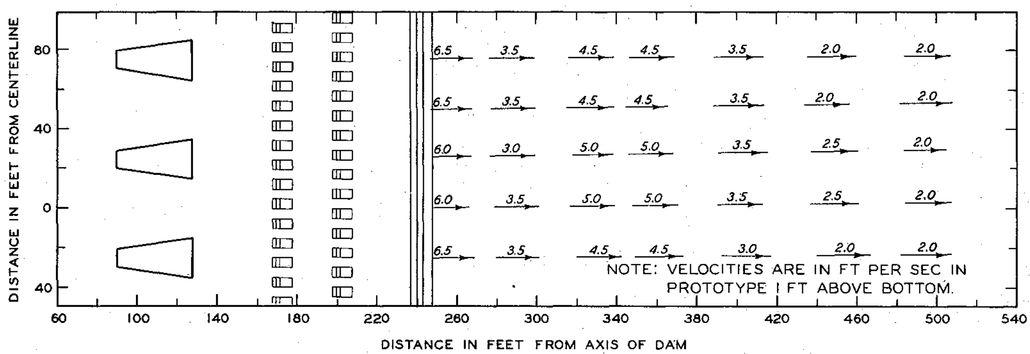
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 2 APRON
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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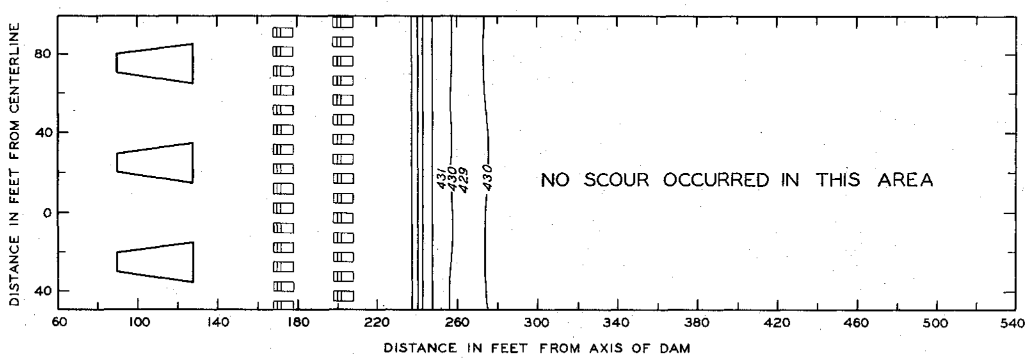


SCOUR PATTERN

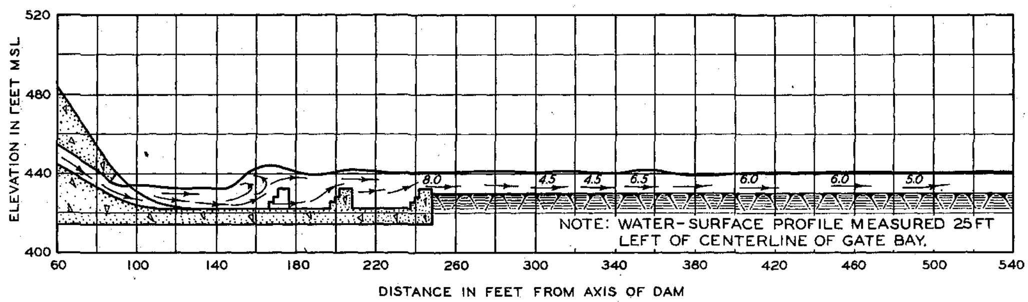
TEST CONDITIONS

DISCHARGE	36,000 CFS
12 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	444.4
BED MOLDED TO ELEVATION	430.0

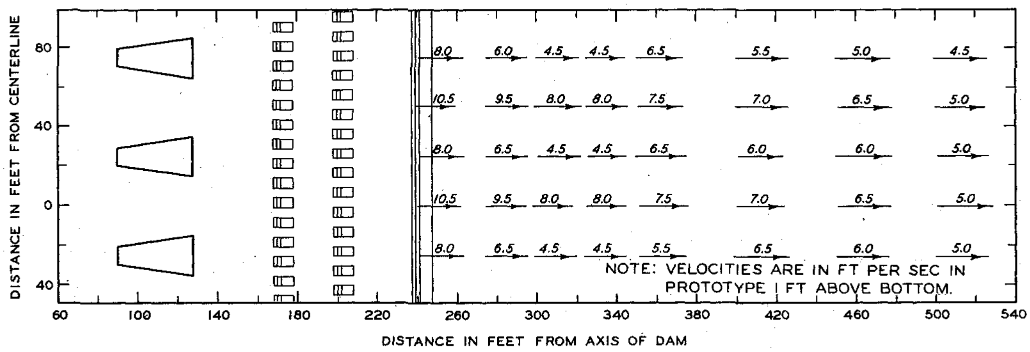
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 2 APRON
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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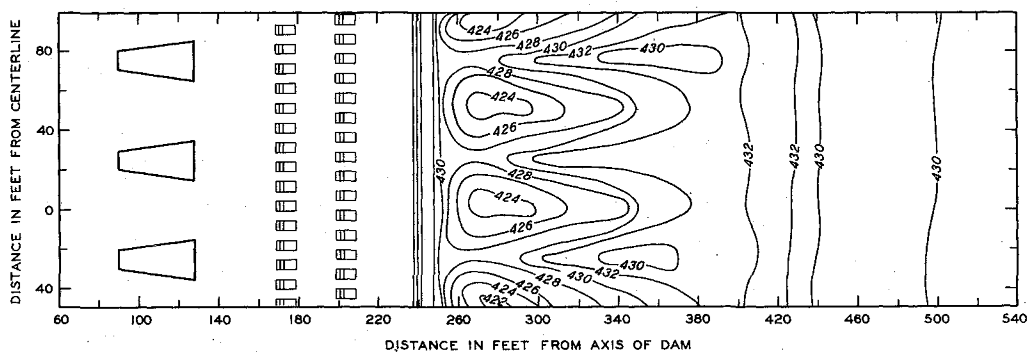


SCOUR PATTERN

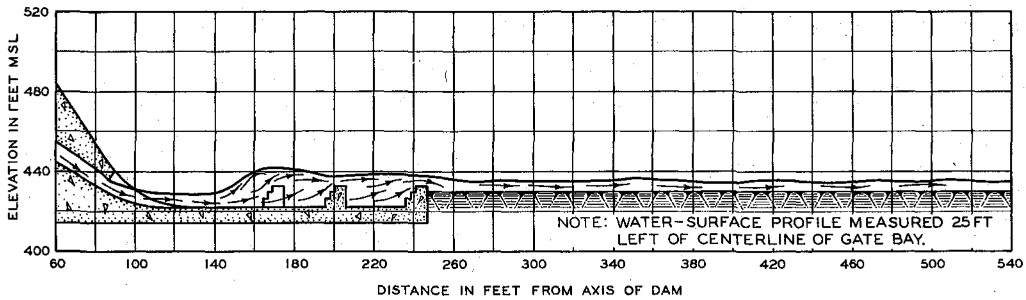
TEST CONDITIONS

DISCHARGE	24,000 CFS
8 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	440.4
BED MOLDED TO ELEVATION	430.0

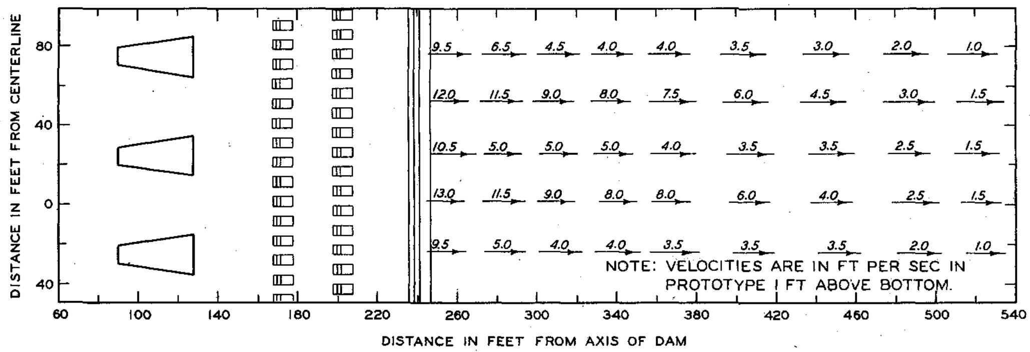
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 2 APRON
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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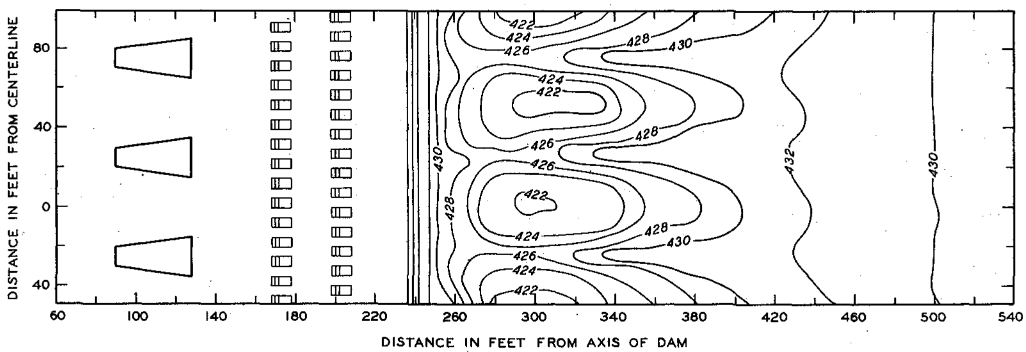


SCOUR PATTERN

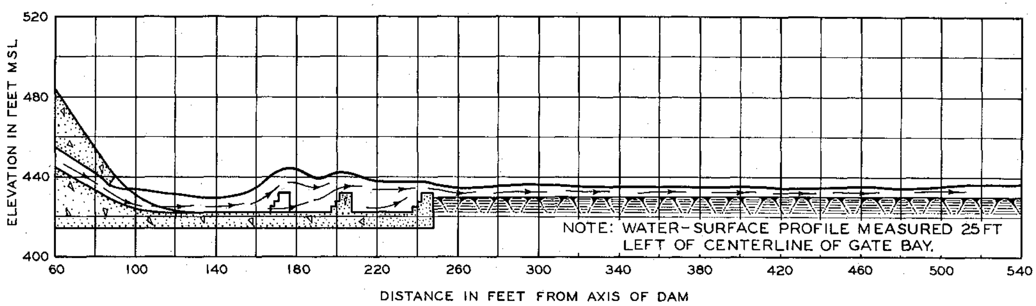
TEST CONDITIONS

DISCHARGE	9,000 CFS
3 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	437.0
BED MOLDED TO ELEVATION	430.0

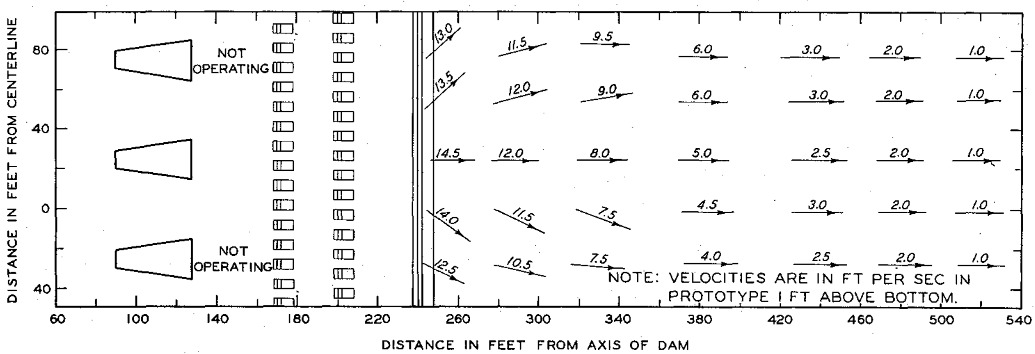
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 2 APRON
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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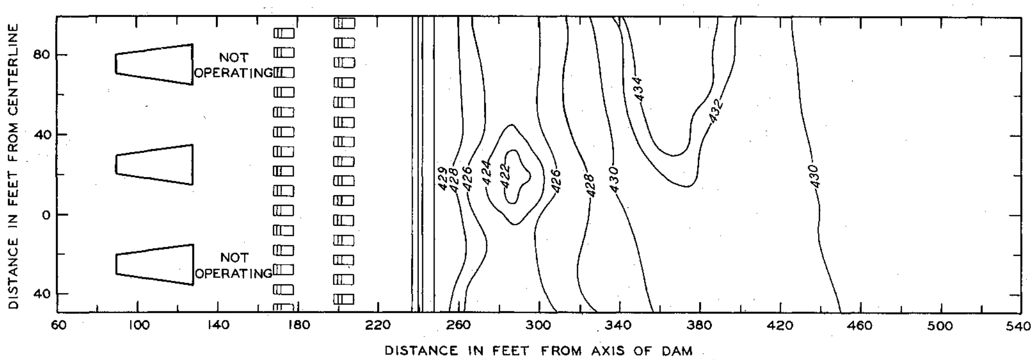


SCOUR PATTERN

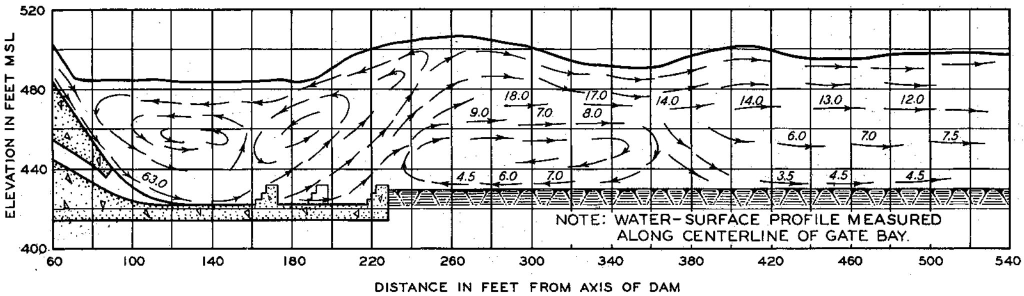
TEST CONDITIONS

DISCHARGE	3,000 CFS
1 CONDUIT OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	436.0
BED MOLDED TO ELEVATION	430.0

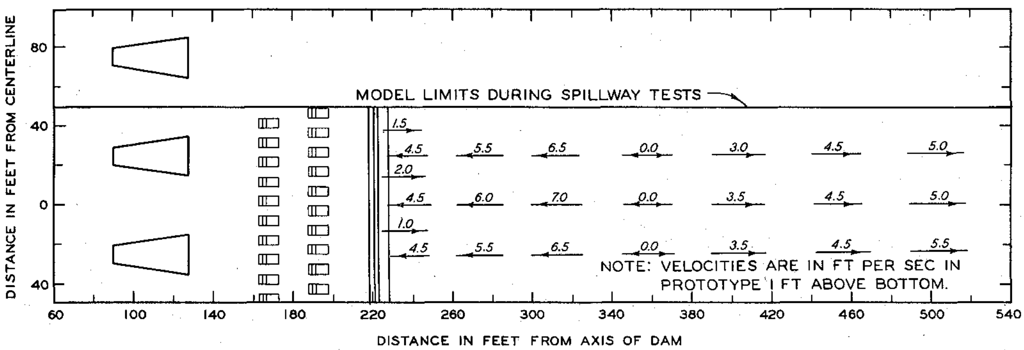
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 2 APRON
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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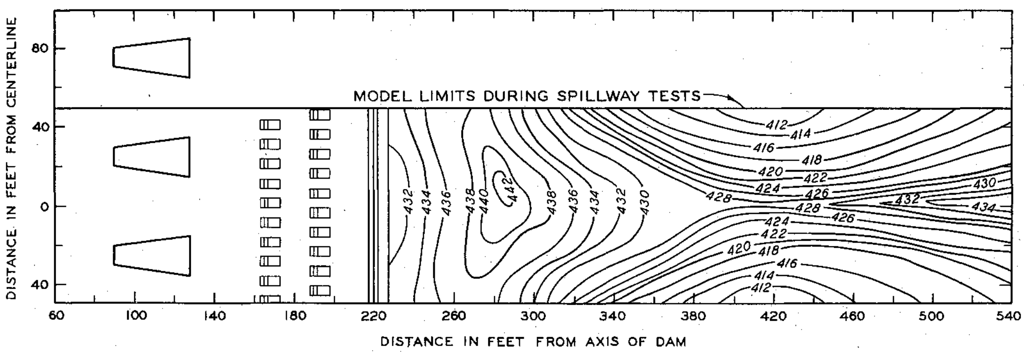


SCOUR PATTERN

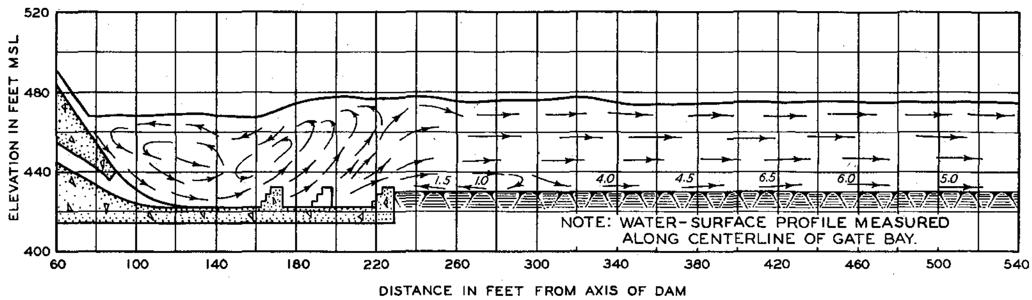
TEST CONDITIONS

DISCHARGE	660,000 CFS
POOL ELEVATION	572.12
TAILWATER ELEVATION	497.60
BED MOLDED TO ELEVATION	430.00

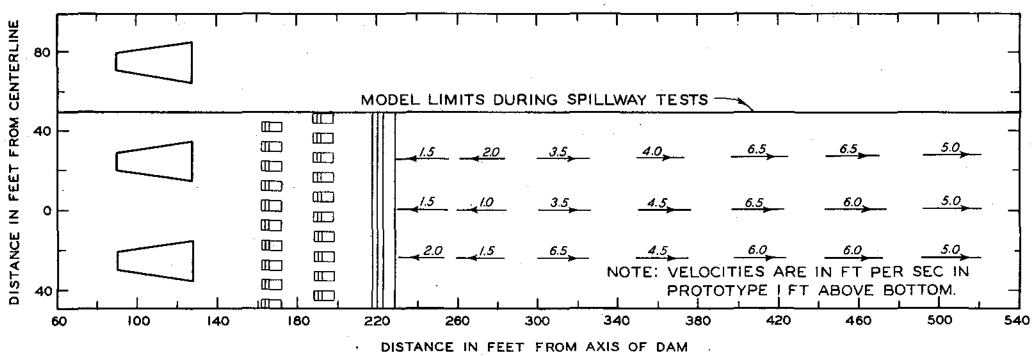
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



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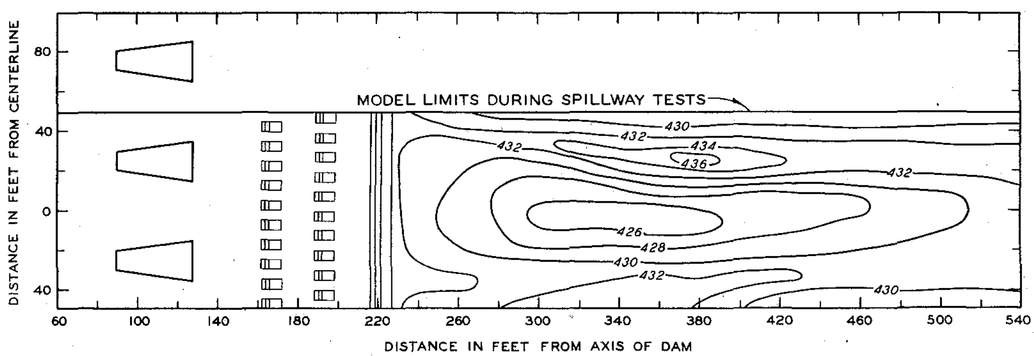


SCOUR PATTERN

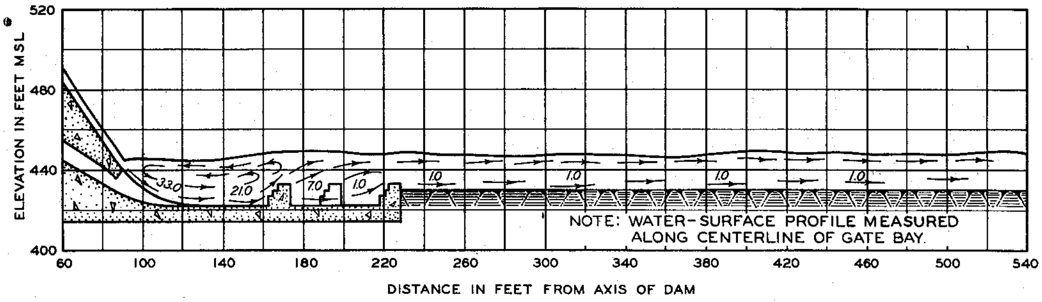
TEST CONDITIONS

DISCHARGE	250,000 CFS
POOL ELEVATION	555.03
TAILWATER ELEVATION	475.35
BED MOLDED TO ELEVATION	430.00

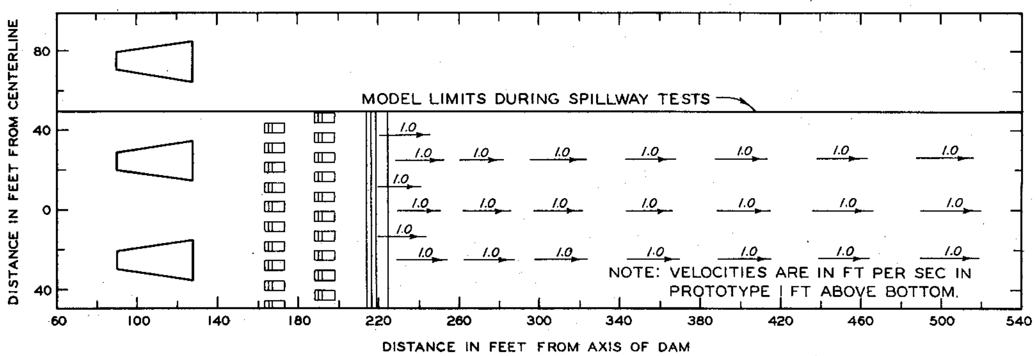
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



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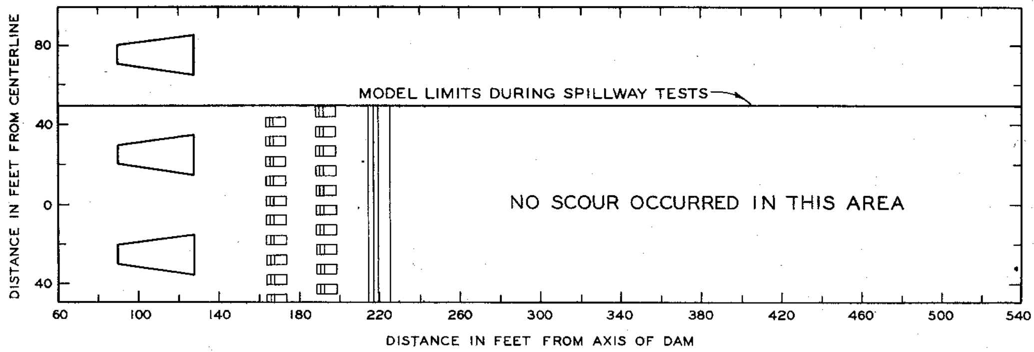


SCOUR PATTERN

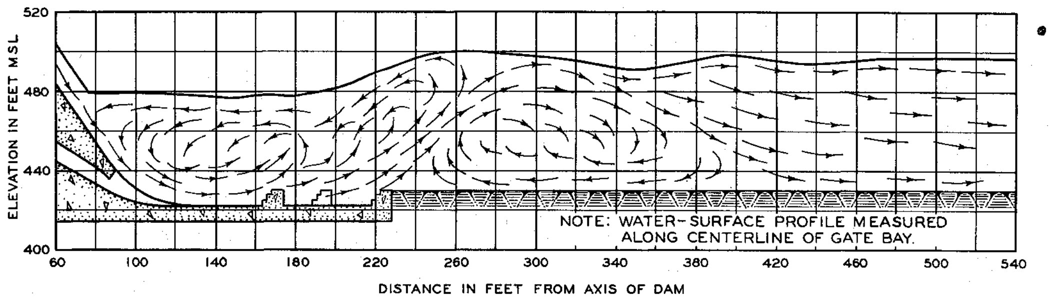
TEST CONDITIONS

DISCHARGE	50,000 CFS
POOL ELEVATION	540.86
TAILWATER ELEVATION	448.30
BED MOLDED TO ELEVATION	430.00

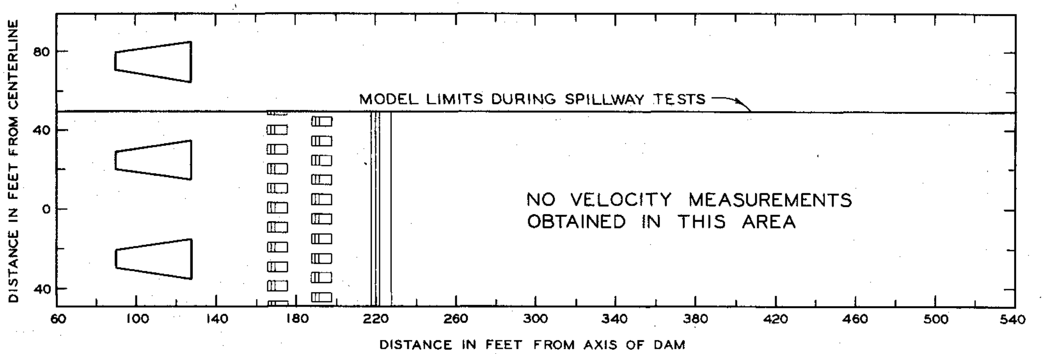
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



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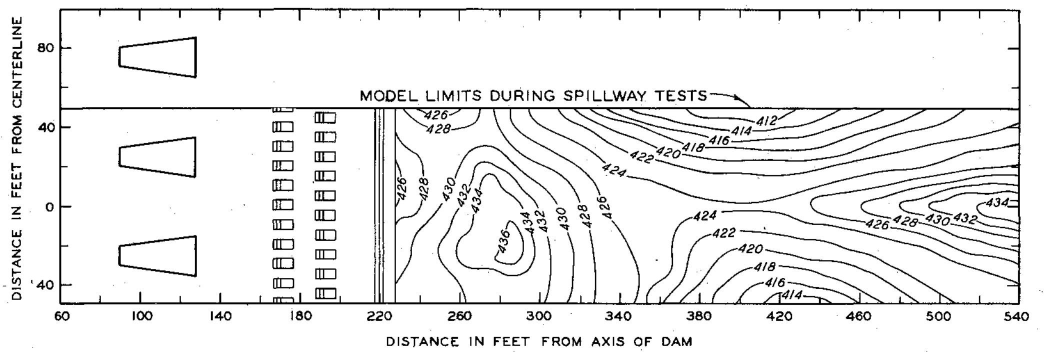


SCOUR PATTERN

TEST CONDITIONS

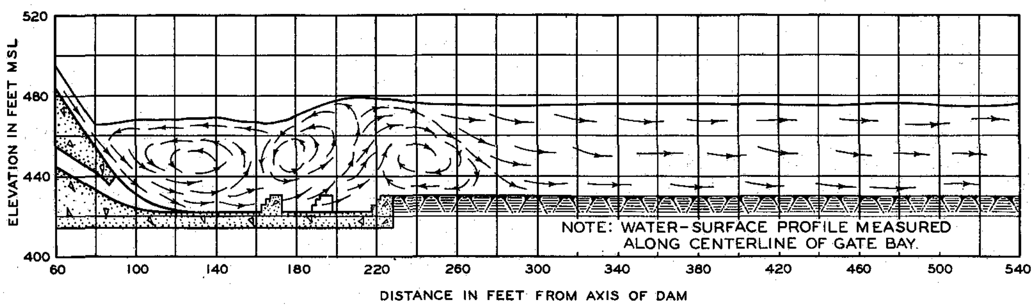
DISCHARGE	660,000 CFS
POOL ELEVATION	572.12
TAILWATER ELEVATION	497.60
BED MOLDED TO ELEVATION	430.0

HEIGHT OF END SILL 8 FT
HEIGHT OF BAFFLE PIERS 8 FT

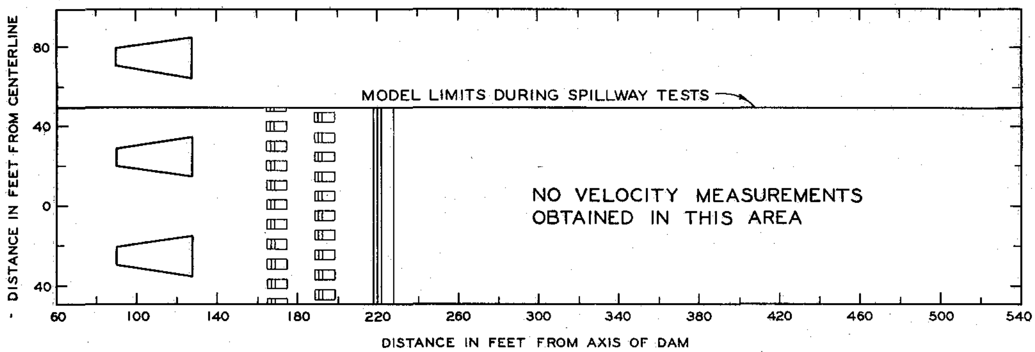
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



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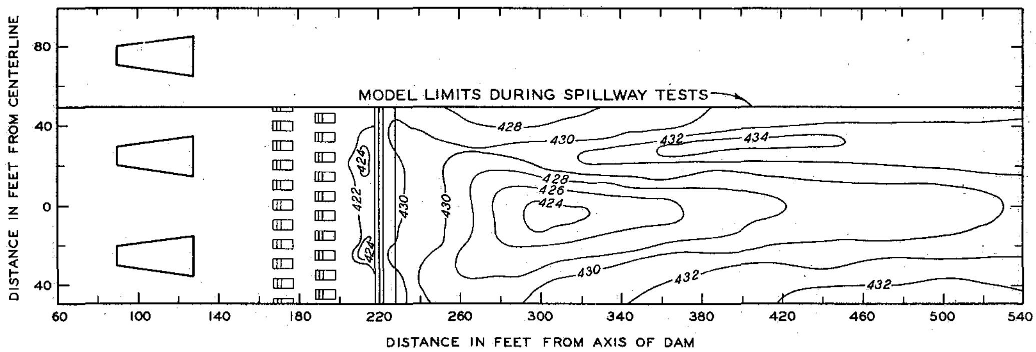


SCOUR PATTERN

TEST CONDITIONS

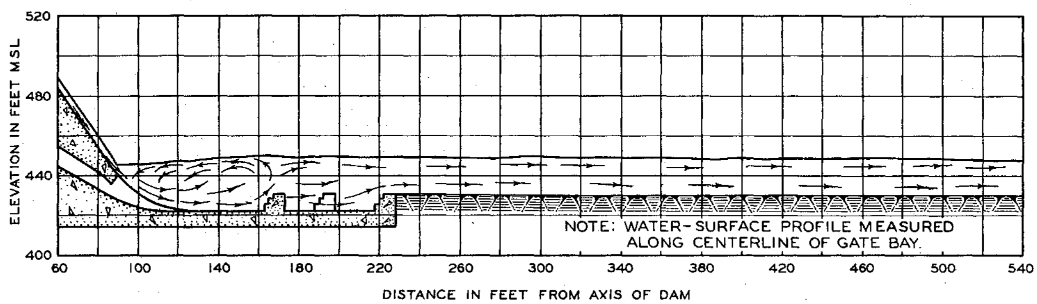
DISCHARGE	250,000 CFS
POOL ELEVATION	555.03
TAILWATER ELEVATION	475.35
BED MOLDED TO ELEVATION	430.0

HEIGHT OF END SILL 8 FT
HEIGHT OF BAFFLE PIERS 8 FT

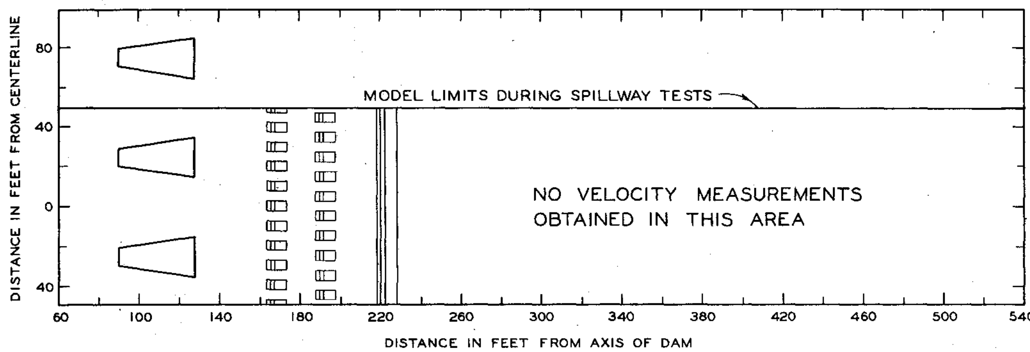
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



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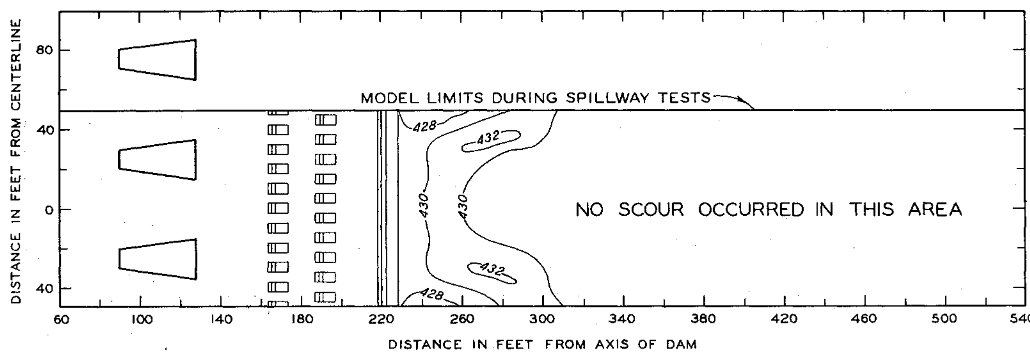


SCOUR PATTERN

TEST CONDITIONS

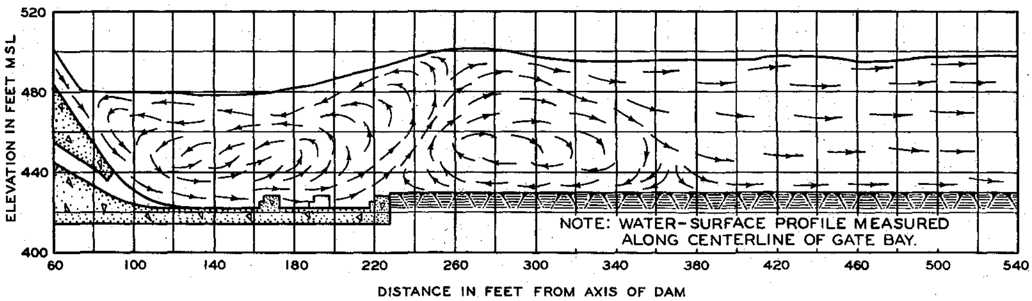
DISCHARGE	50,000 CFS
POOL ELEVATION	540.86
TAILWATER ELEVATION	448.30
BED MOLDED TO ELEVATION	430.0

HEIGHT OF END SILL 8 FT
HEIGHT OF BAFFLE PIERS 8FT.

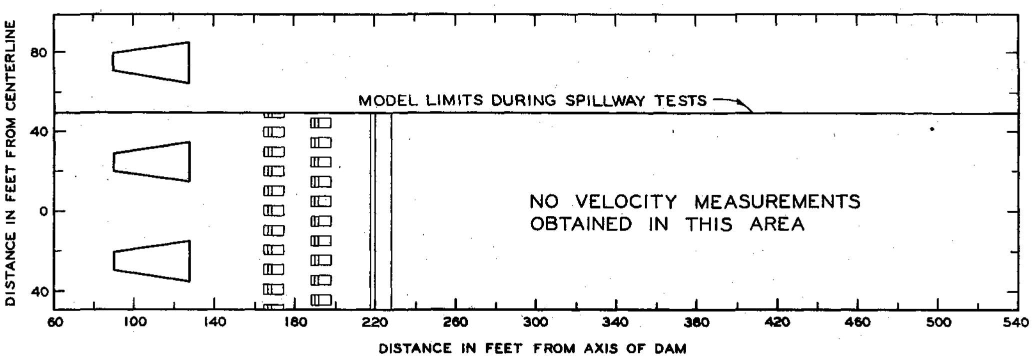
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



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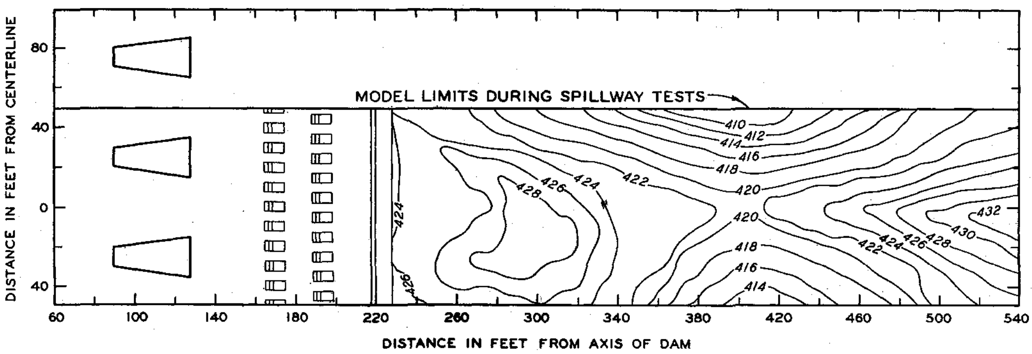


SCOUR PATTERN

TEST CONDITIONS

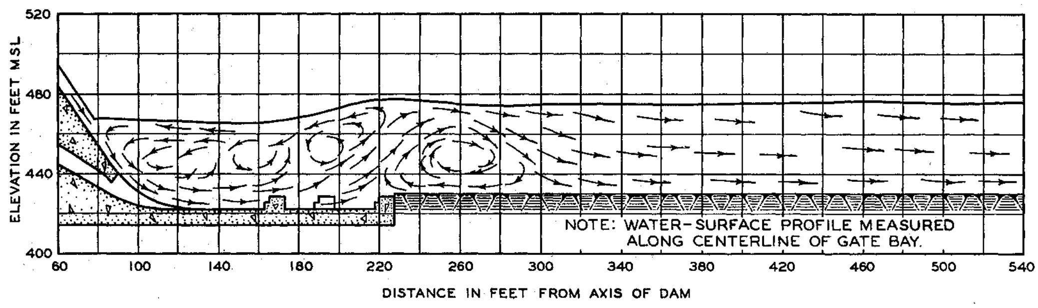
DISCHARGE	660,000 CFS
POOL ELEVATION	572.12
TAILWATER ELEVATION	497.60
BED MOLDED TO ELEVATION	430.0

HEIGHT OF END SILL 6 FT
HEIGHT OF BAFFLE PIERS 6 FT

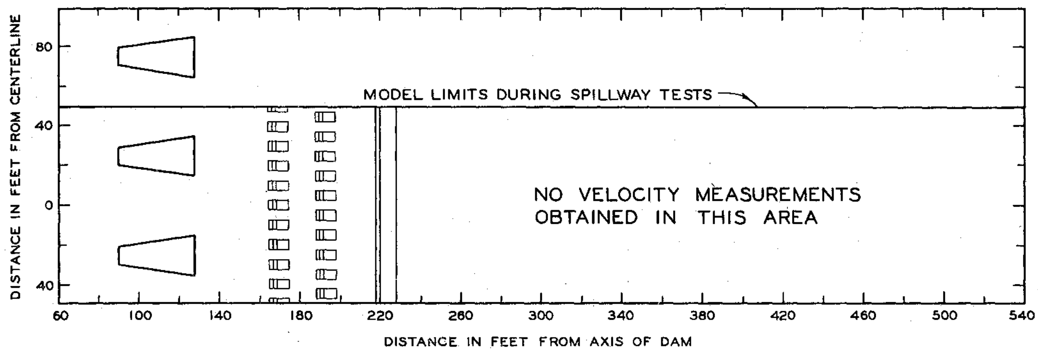
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



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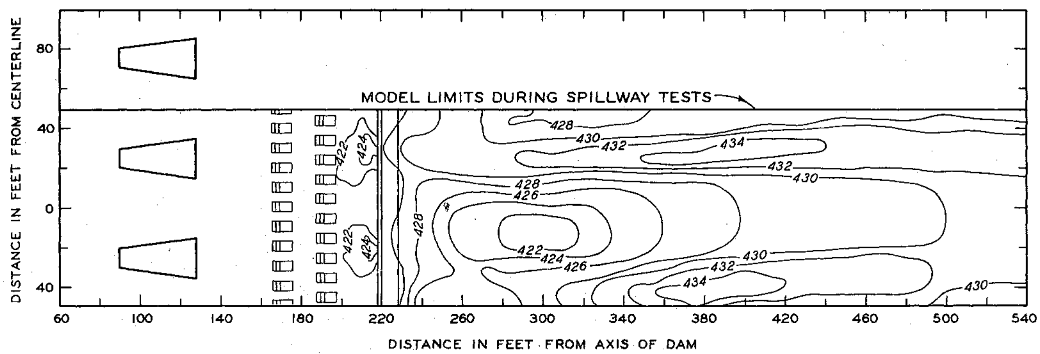


SCOUR PATTERN

TEST CONDITIONS

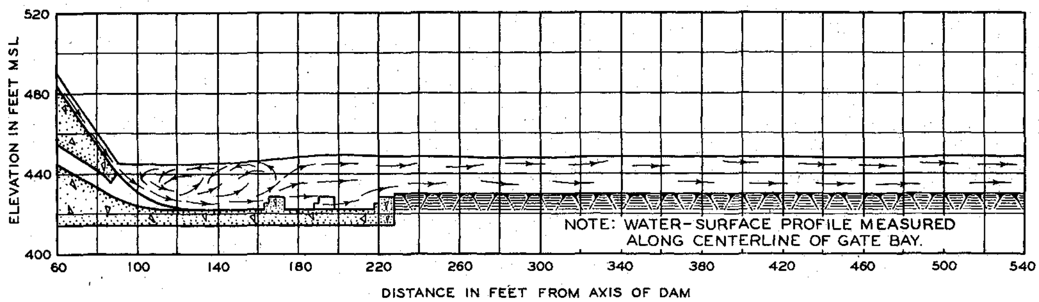
DISCHARGE	250,000 CFS
POOL ELEVATION	555.03
TAILWATER ELEVATION	475.35
BED MOLDED TO ELEVATION	430.0

HEIGHT OF END SILL 6 FT
HEIGHT OF BAFFLE PIERS 6 FT

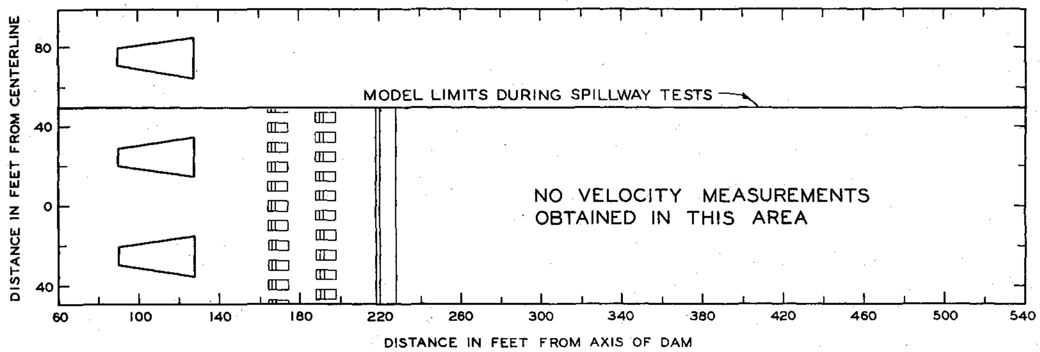
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
SPILLWAY FLOW



WATER-SURFACE PROFILE AND CURRENTS



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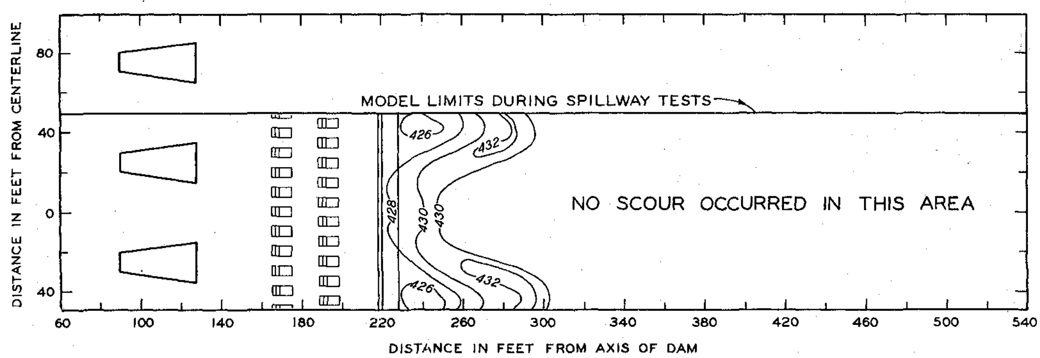


SCOUR PATTERN

TEST CONDITIONS

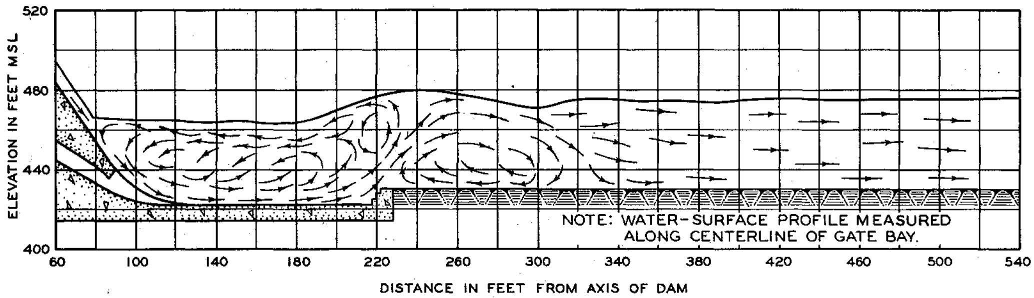
DISCHARGE	50,000 CFS
POOL ELEVATION	540.86
TAILWATER ELEVATION	448.30
BED MOLDED TO ELEVATION	430.0

HEIGHT OF END SILL 6 FT
HEIGHT OF BAFFLE PIERS 6 FT

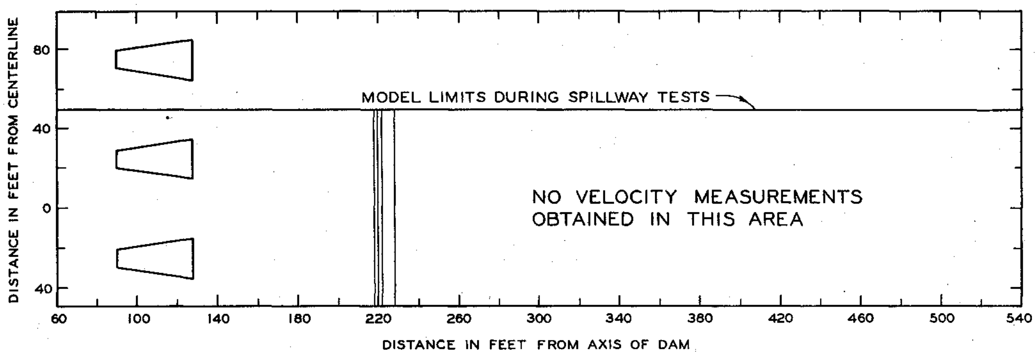
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
SPILLWAY FLOW



WATER - SURFACE PROFILE AND CURRENTS



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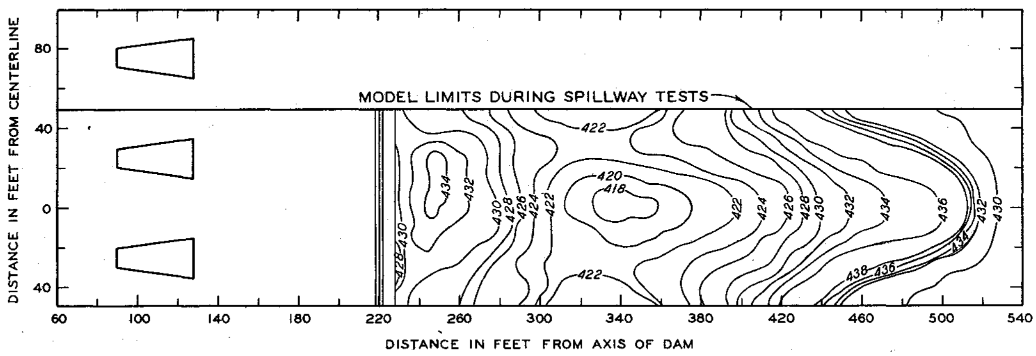


SCOUR PATTERN

TEST CONDITIONS

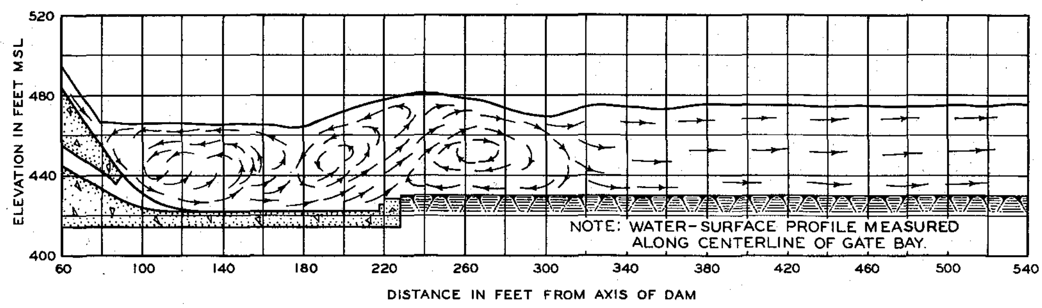
DISCHARGE	250,000 CFS
POOL ELEVATION	555.03
TAILWATER ELEVATION	475.35
BED MOLDED TO ELEVATION	430.0

HEIGHT OF END SILL 8 FT
NO BAFFLE PIERS

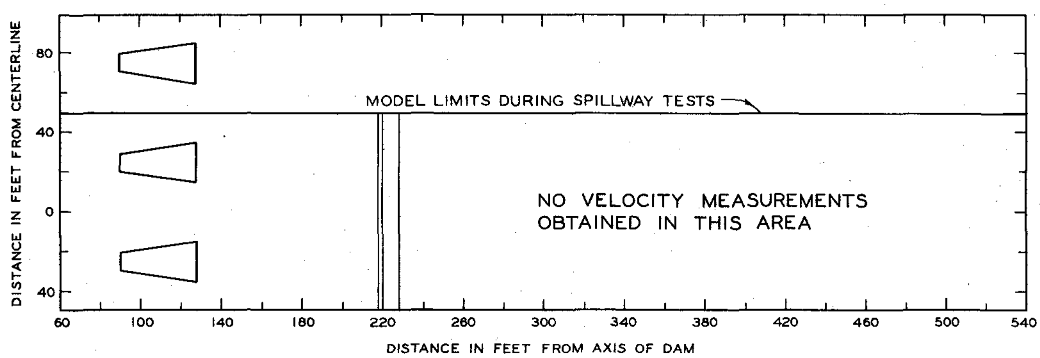
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

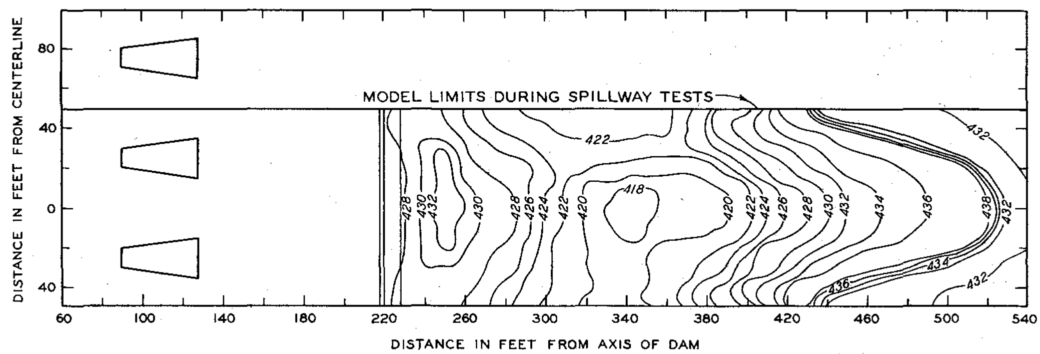
TYPE 3 APRON
SPILLWAY FLOW



WATER - SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

TEST CONDITIONS

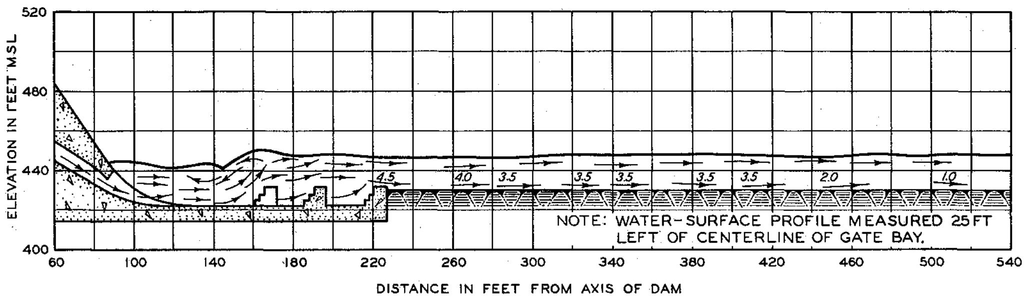
DISCHARGE	250,000 CFS
POOL ELEVATION	555.03
TAILWATER ELEVATION	475.35
BED MOLDED TO ELEVATION	430.0

HEIGHT OF END SILL 6 FT.
NO BAFFLE PIERS

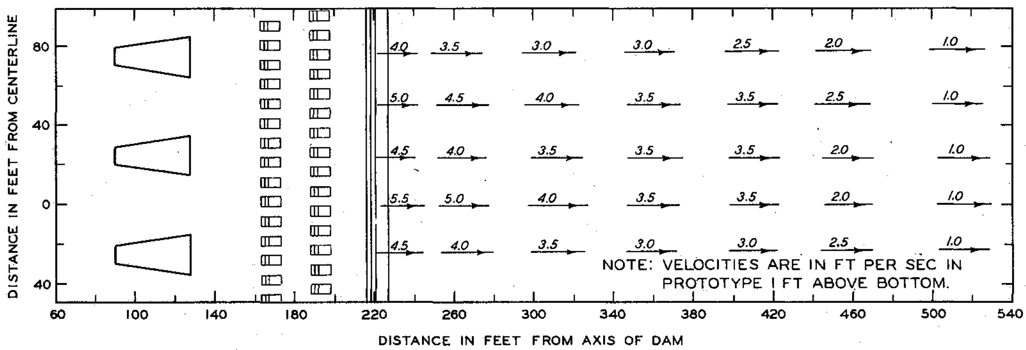
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

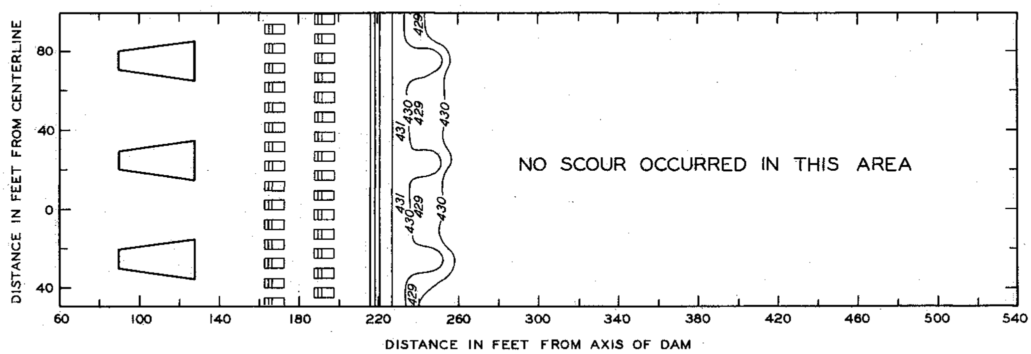
TYPE 3 APRON
SPILLWAY FLOW



WATER - SURFACE PROFILE AND CURRENTS



BOTTOM VELOCITY DISTRIBUTION



SCOUR PATTERN

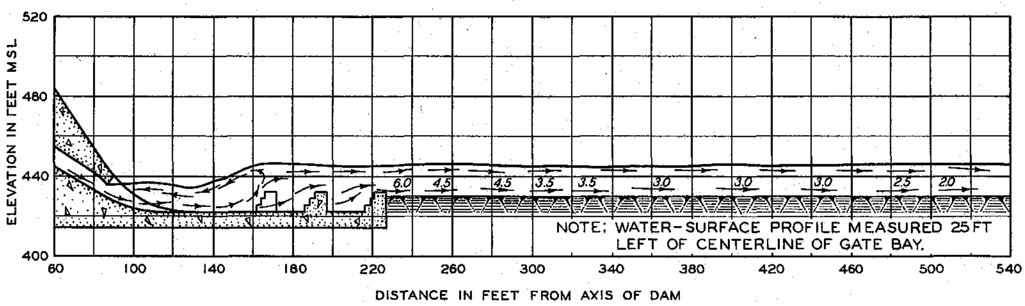
TEST CONDITIONS

DISCHARGE	46,400 CFS
16 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	448.0
BED MOLDED TO ELEVATION	430.0

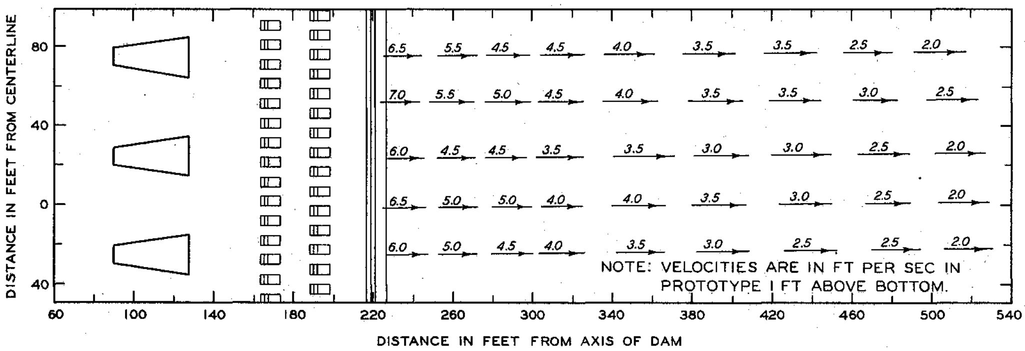
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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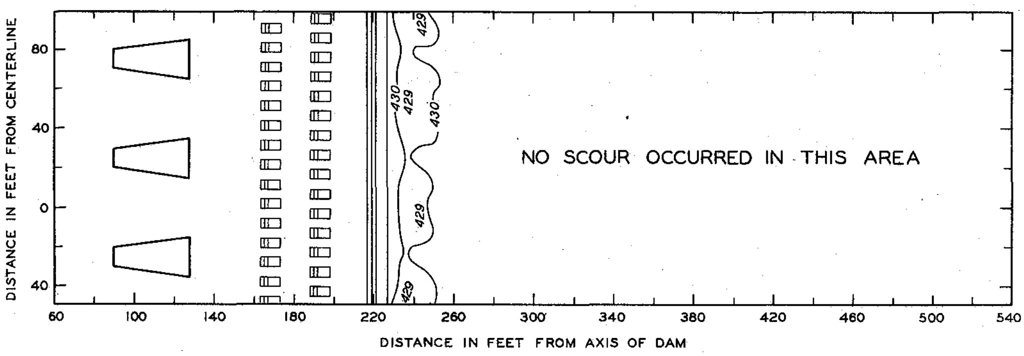


SCOUR PATTERN

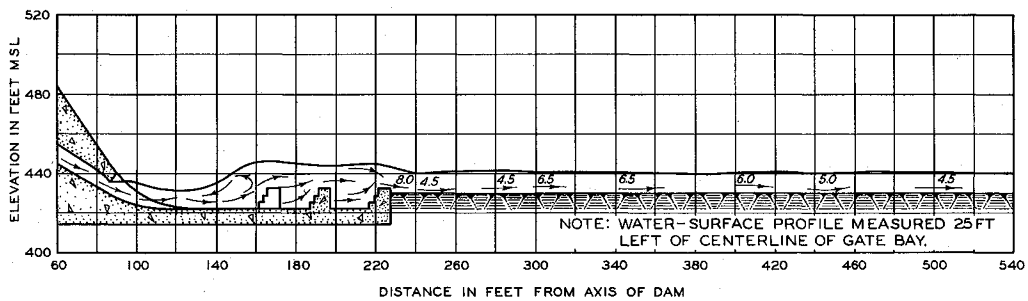
TEST CONDITIONS

DISCHARGE	36,000 CFS
12 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	444.4
BED MOLDED TO ELEVATION	430.0

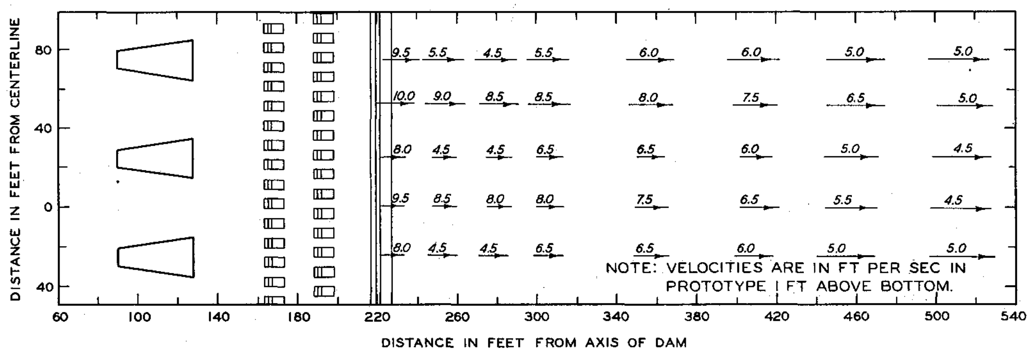
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
CONDUIT FLOW



WATER - SURFACE PROFILE AND CURRENTS



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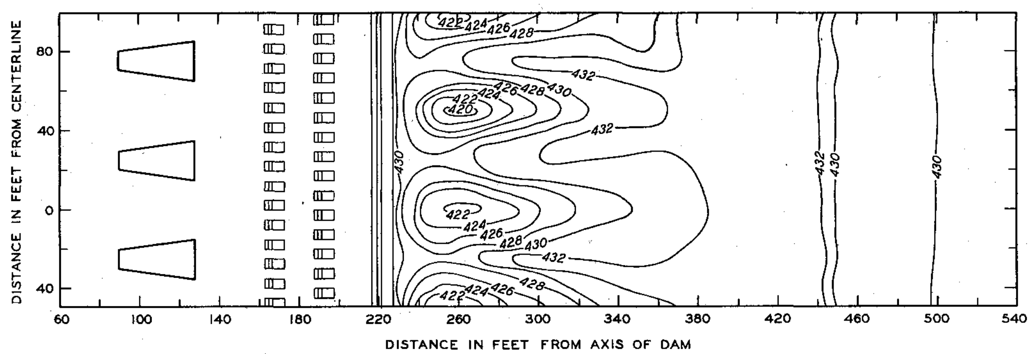


SCOUR PATTERN

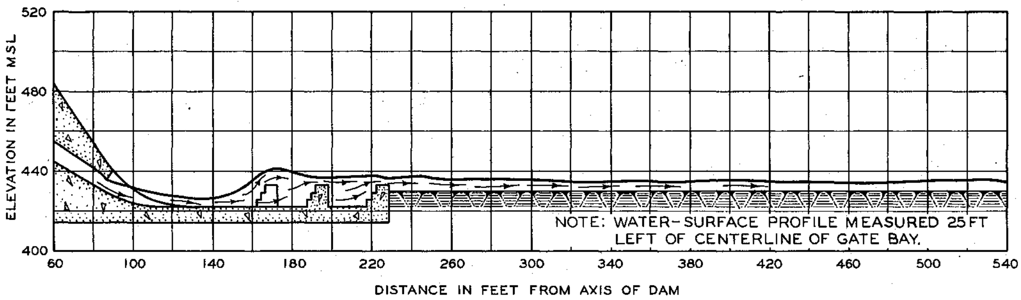
TEST CONDITIONS

DISCHARGE	24,000 CFS
8 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	440.4
BED MOLDED TO ELEVATION	430.0

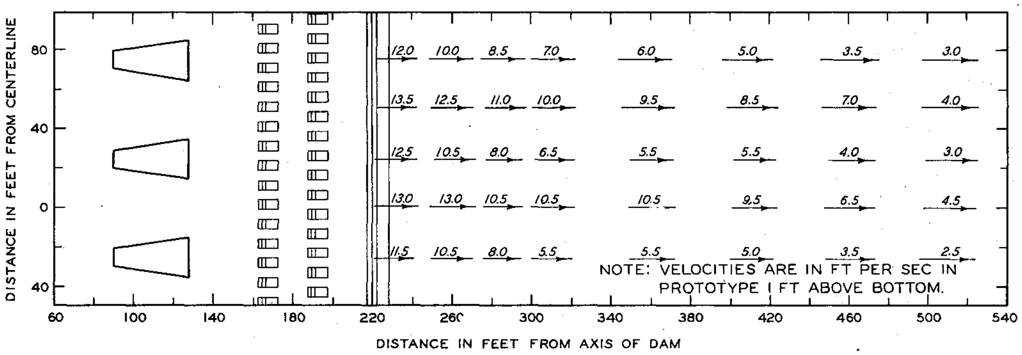
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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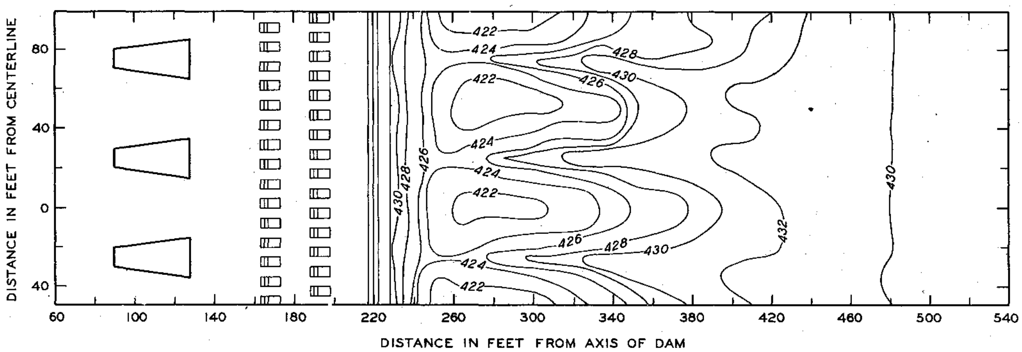


SCOUR PATTERN

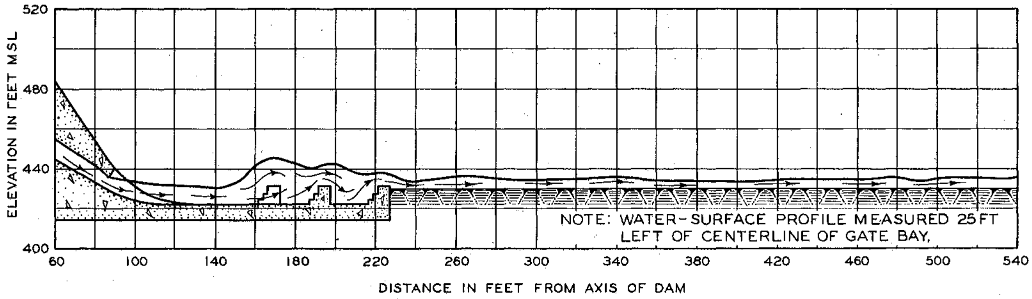
TEST CONDITIONS

DISCHARGE	9,000 CFS
3 CONDUITS OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	437.0
BED MOLDED TO ELEVATION	430.0

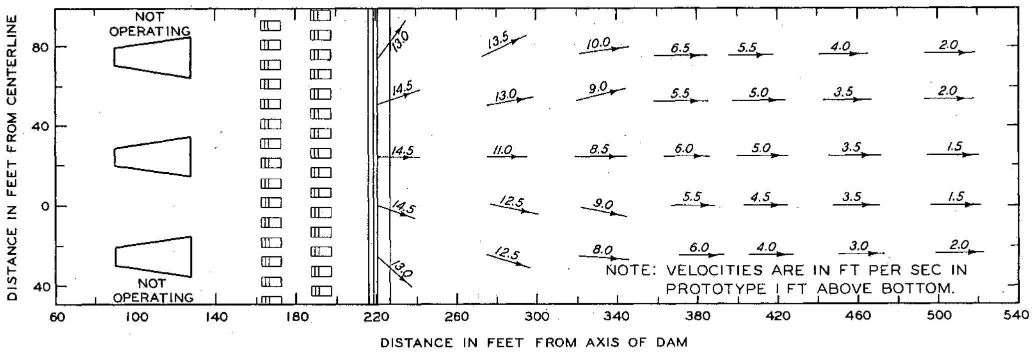
MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
CONDUIT FLOW



WATER-SURFACE PROFILE AND CURRENTS



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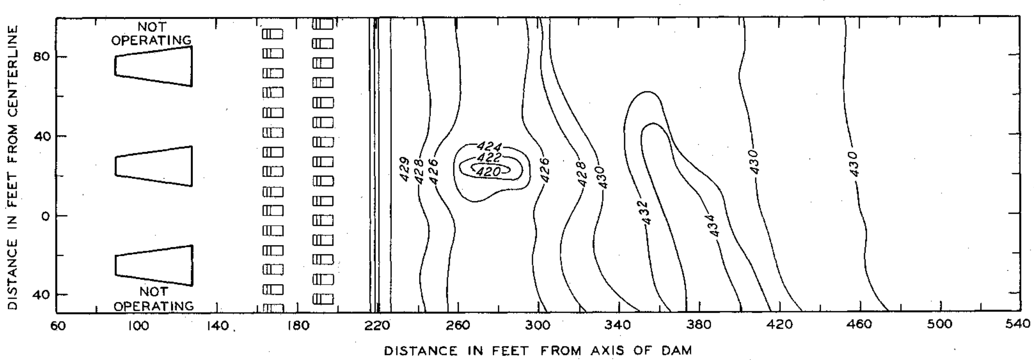

SCOUR PATTERN

TEST CONDITIONS

DISCHARGE	3,000 CFS
1 CONDUIT OPERATING	
POOL ELEVATION	571.0
TAILWATER ELEVATION	436.0
BED MOLDED TO ELEVATION	430.0

MODEL STUDY OF SPILLWAY FOR WHITNEY DAM
BRAZOS RIVER, TEXAS

FLOW CHARACTERISTICS

TYPE 3 APRON
CONDUIT FLOW